GRAVITY First Results and Perspectives

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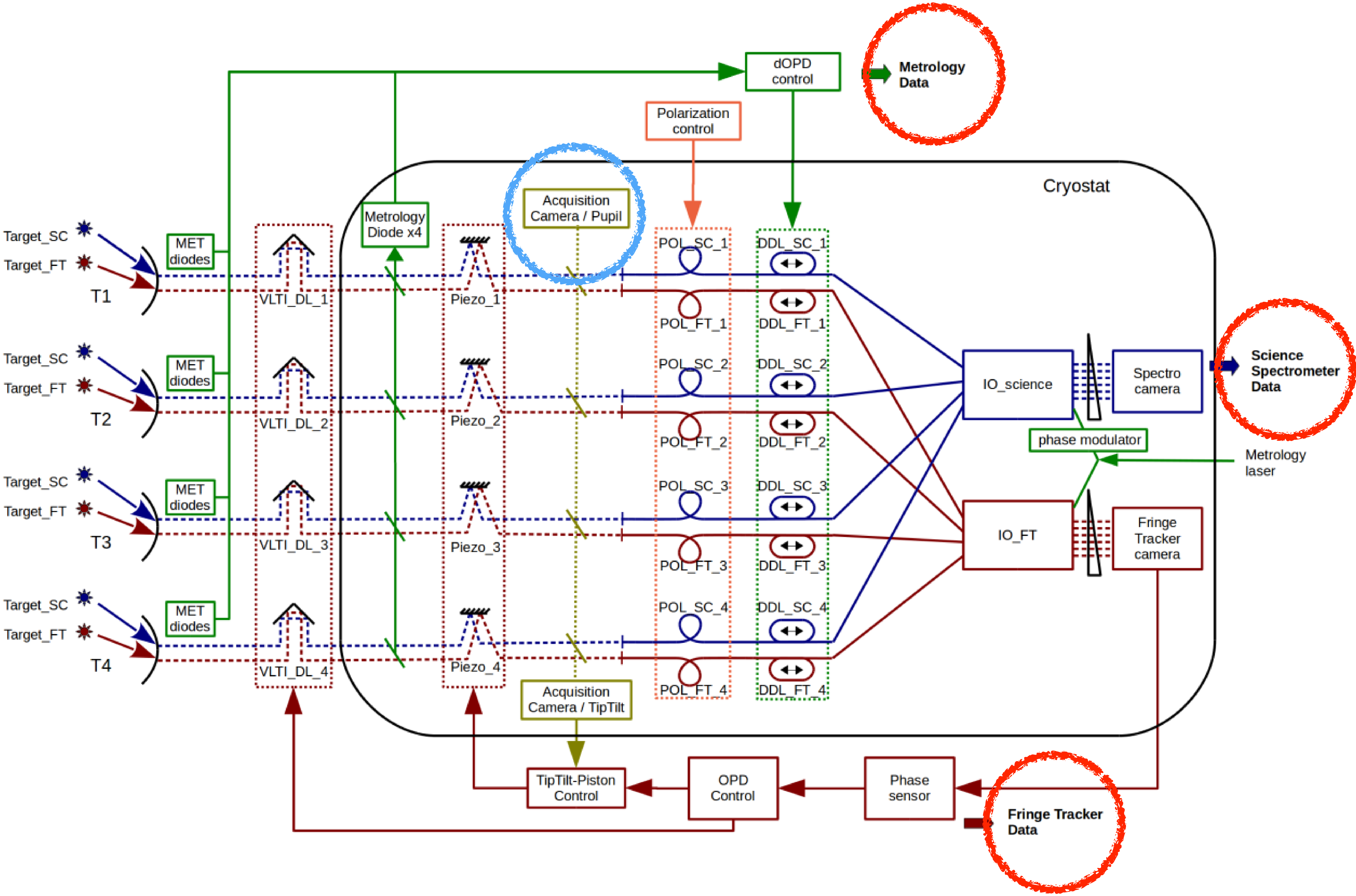
Capabilities and limitations

- 4-telescope dual field beam combiner
- K band (full), 3 resolutions LOW, MEDIUM, HIGH
  R=22 (11 pixels), 500 (210 pixels), 4000 (1740 pixels)
- SPLIT or COMBINED polarizations
- single or dual field < 2” for UTs or < 5" for ATs
- dual field astrometry
- m_K~7 limiting magnitude of FT (ATs) to ~10 (UTs)
- Limit of m_K~18 for the science combiner in dual field

GRAVITY data sources



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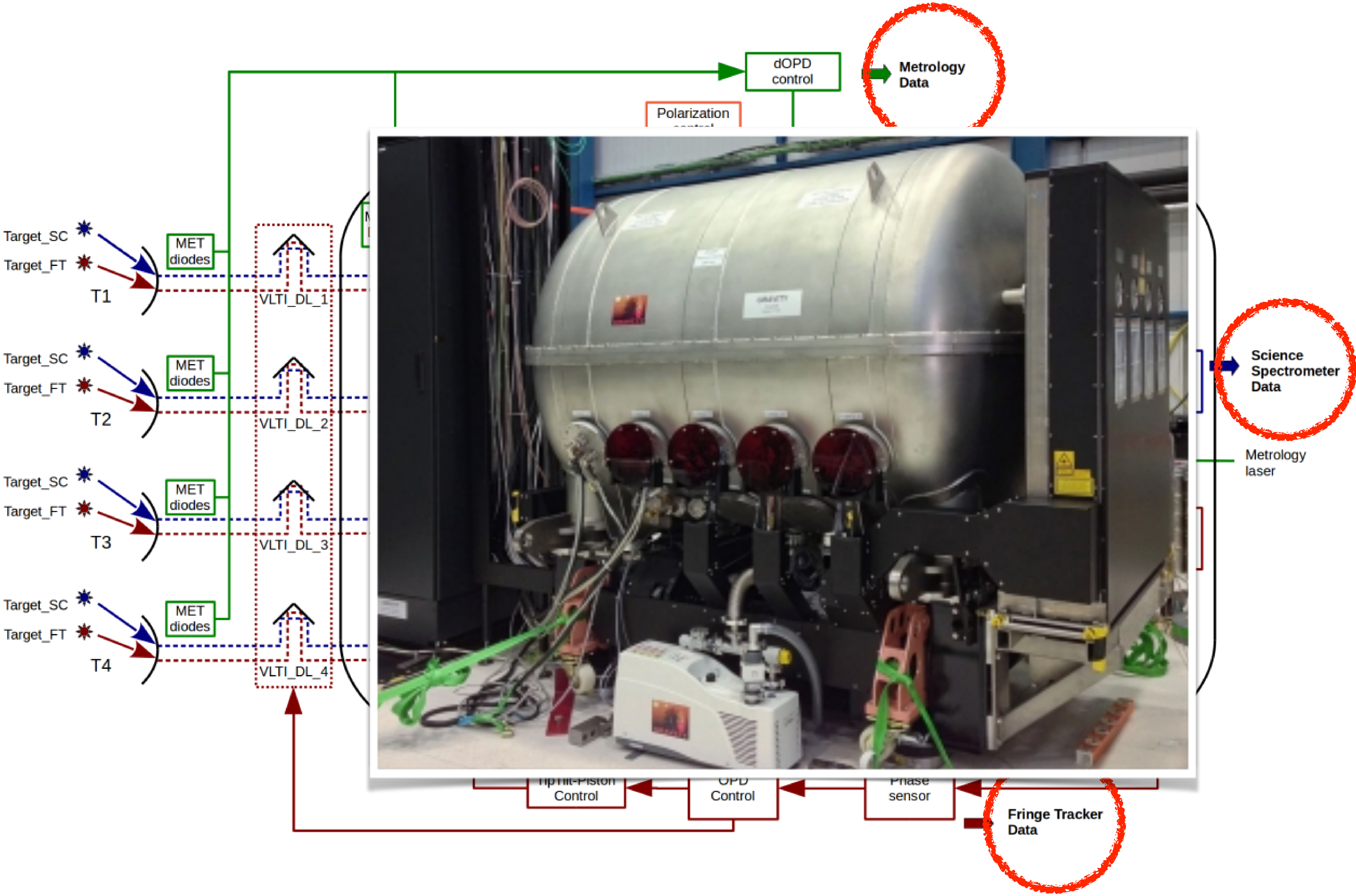

Overview

- The Galactic Center, Sgr A* flaring
- Imaging / modeling: η Carinae and SS 433
- Spectro-astrometry: BP Crucis
- Astrometry: Gliese 65 AB and α Centauri AB

Image: ESO/S. Brunier

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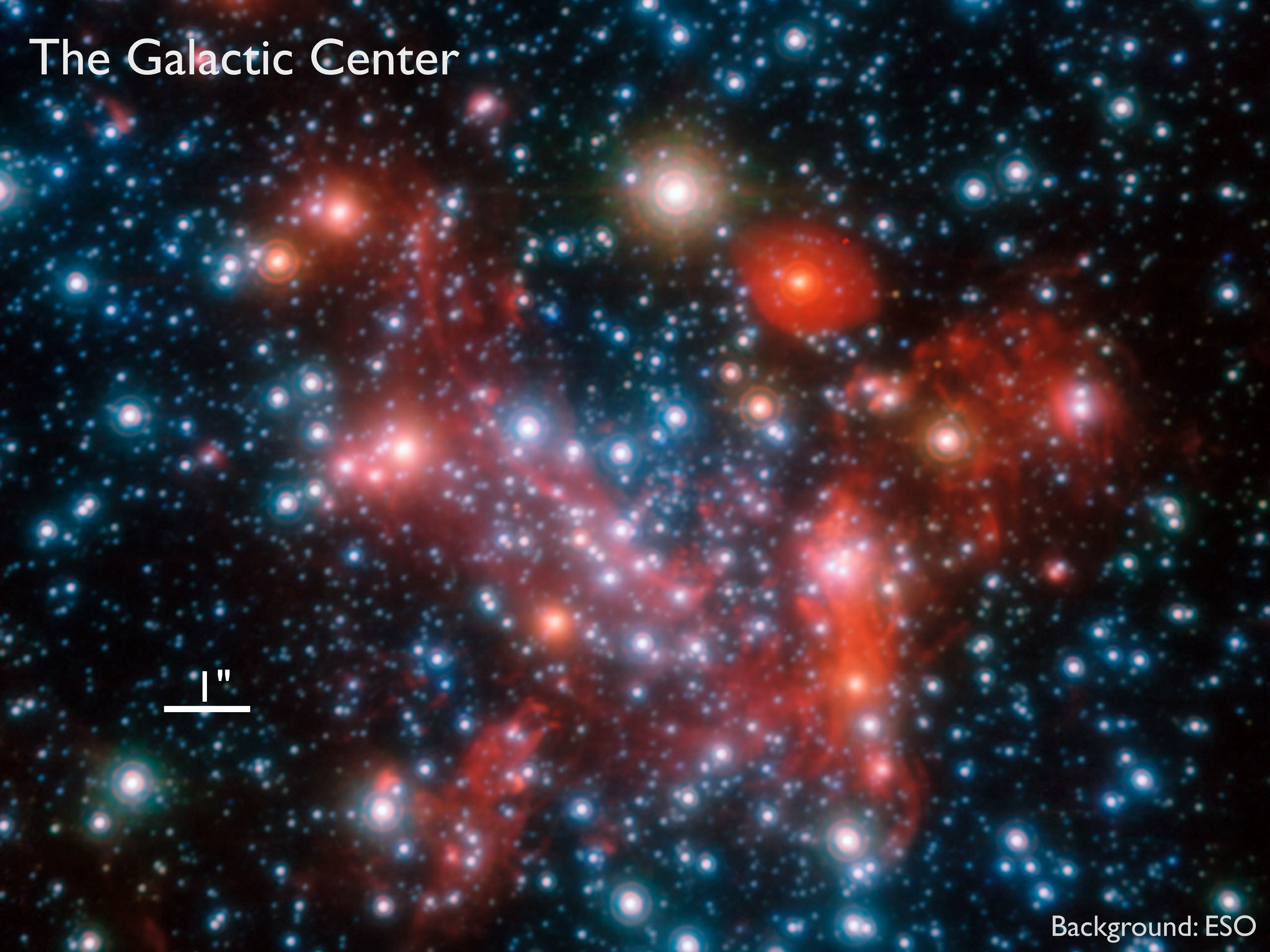
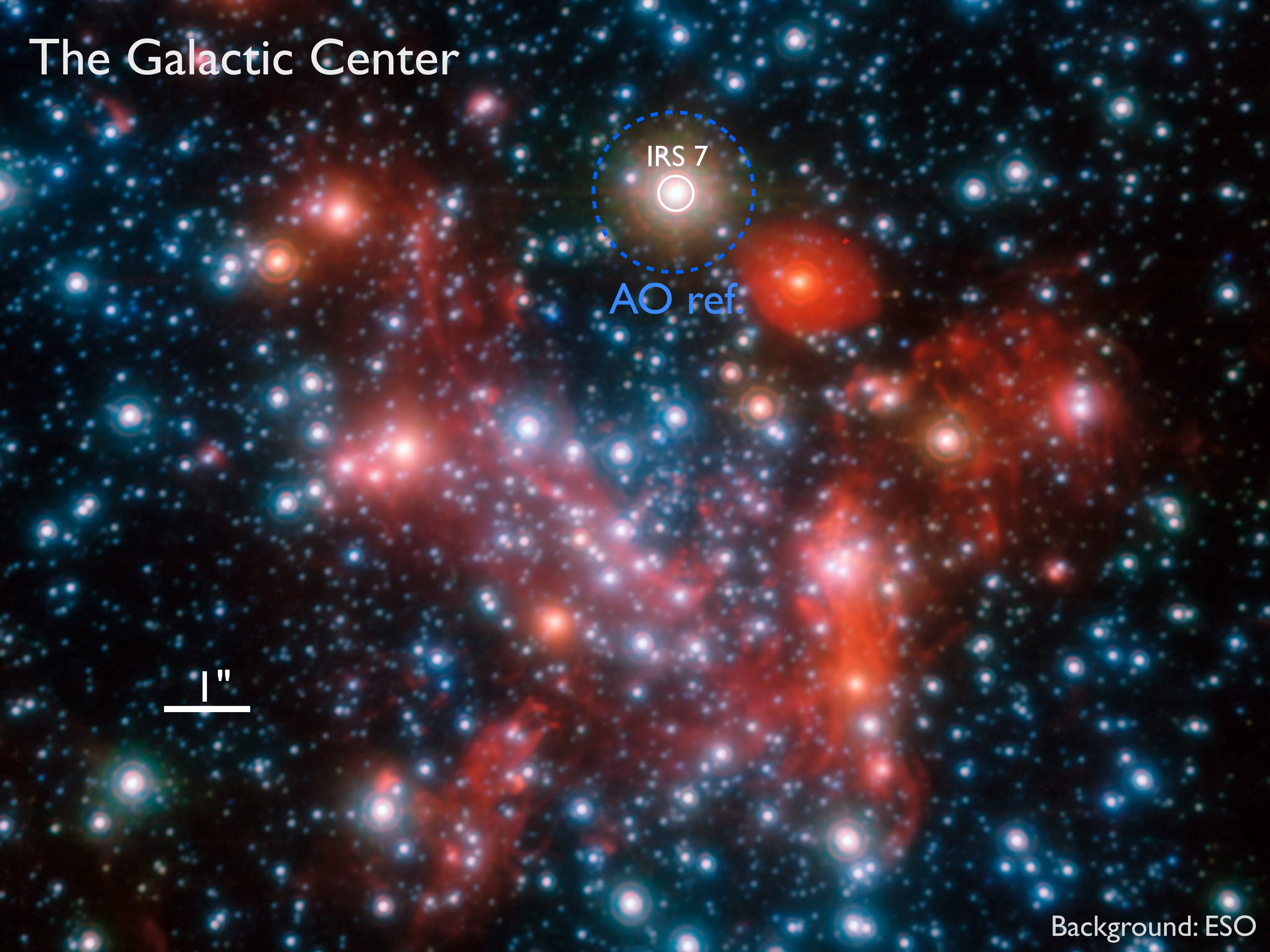
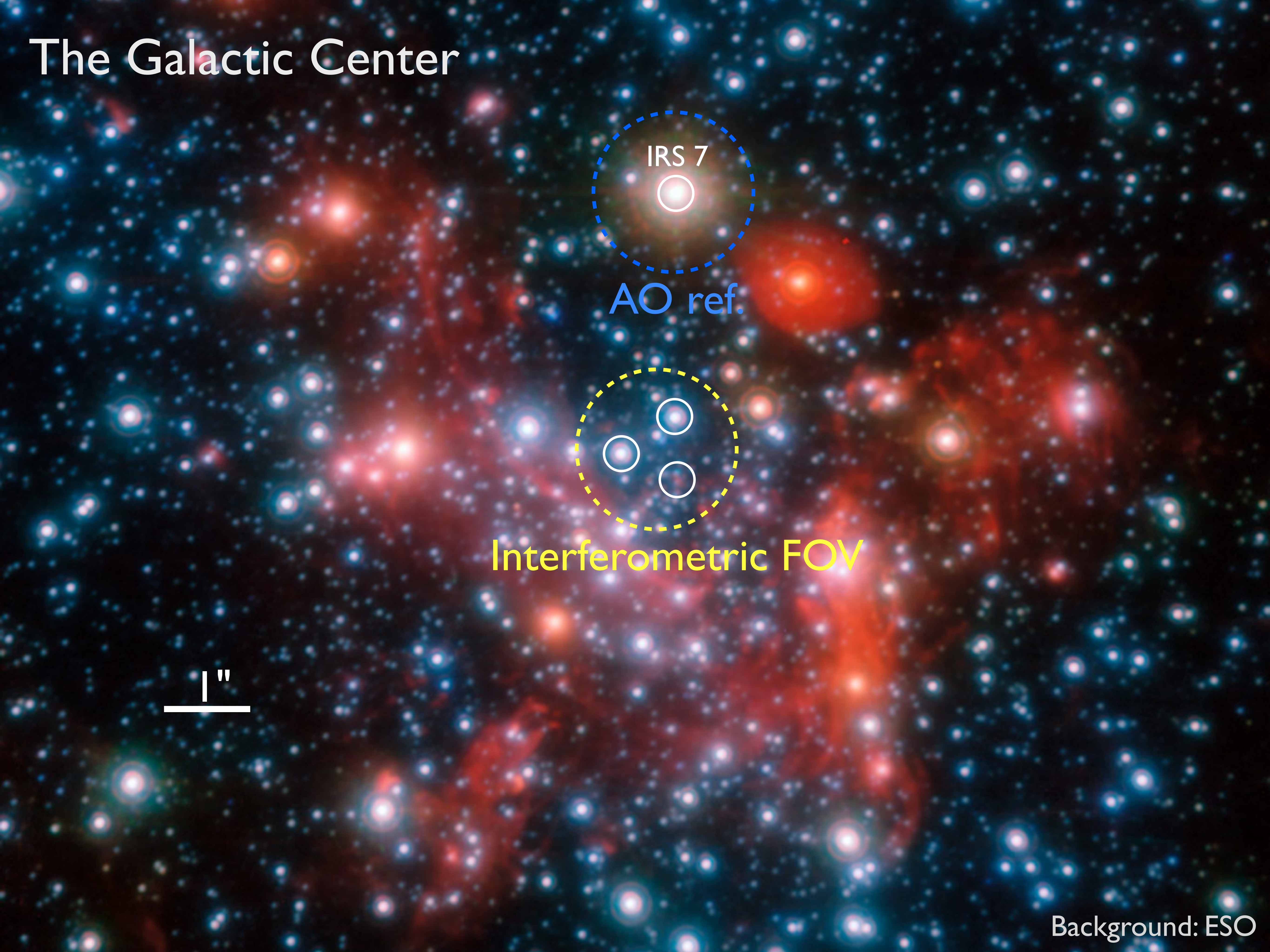
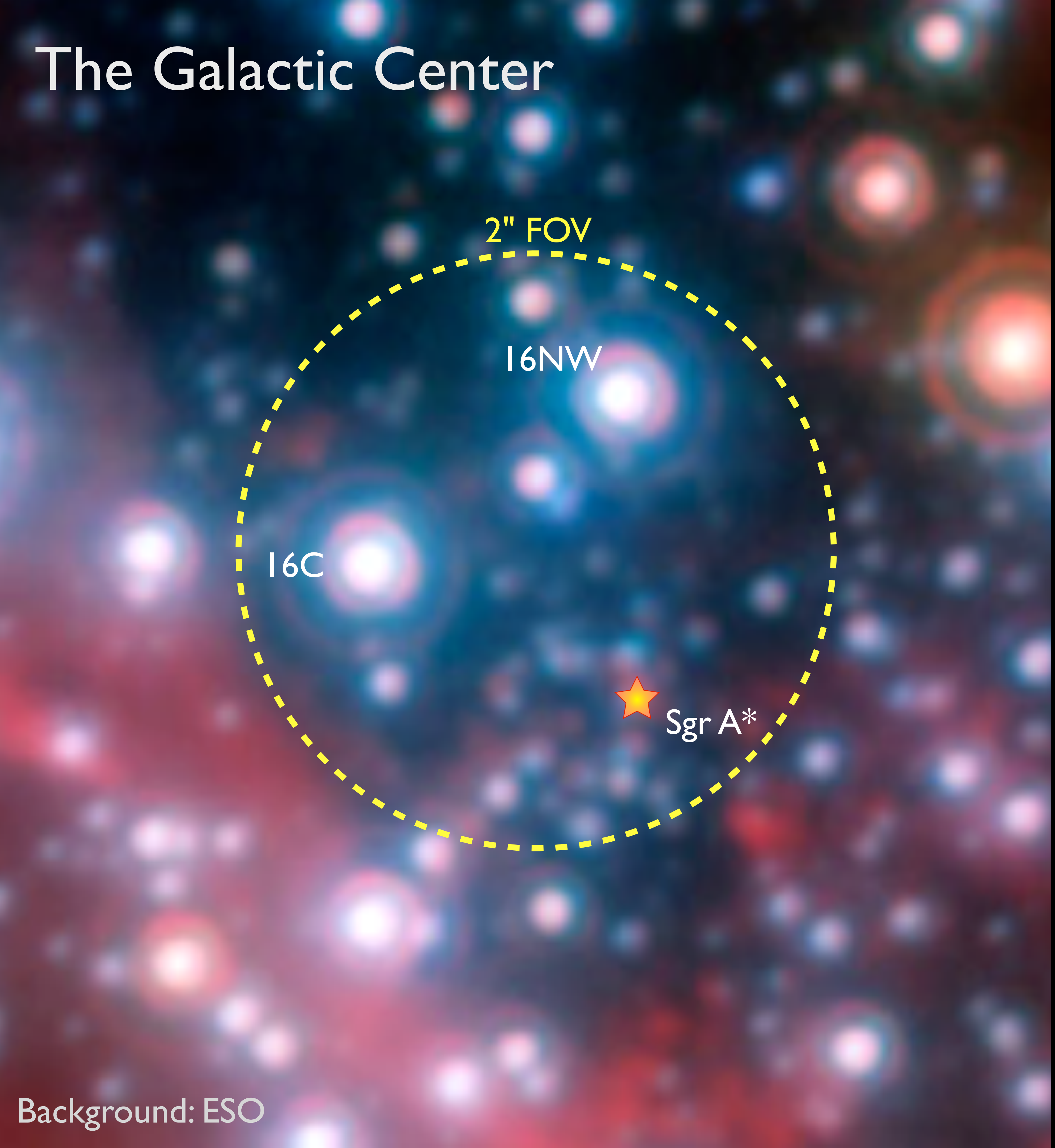

The Galactic Center
1"
Background: ESO

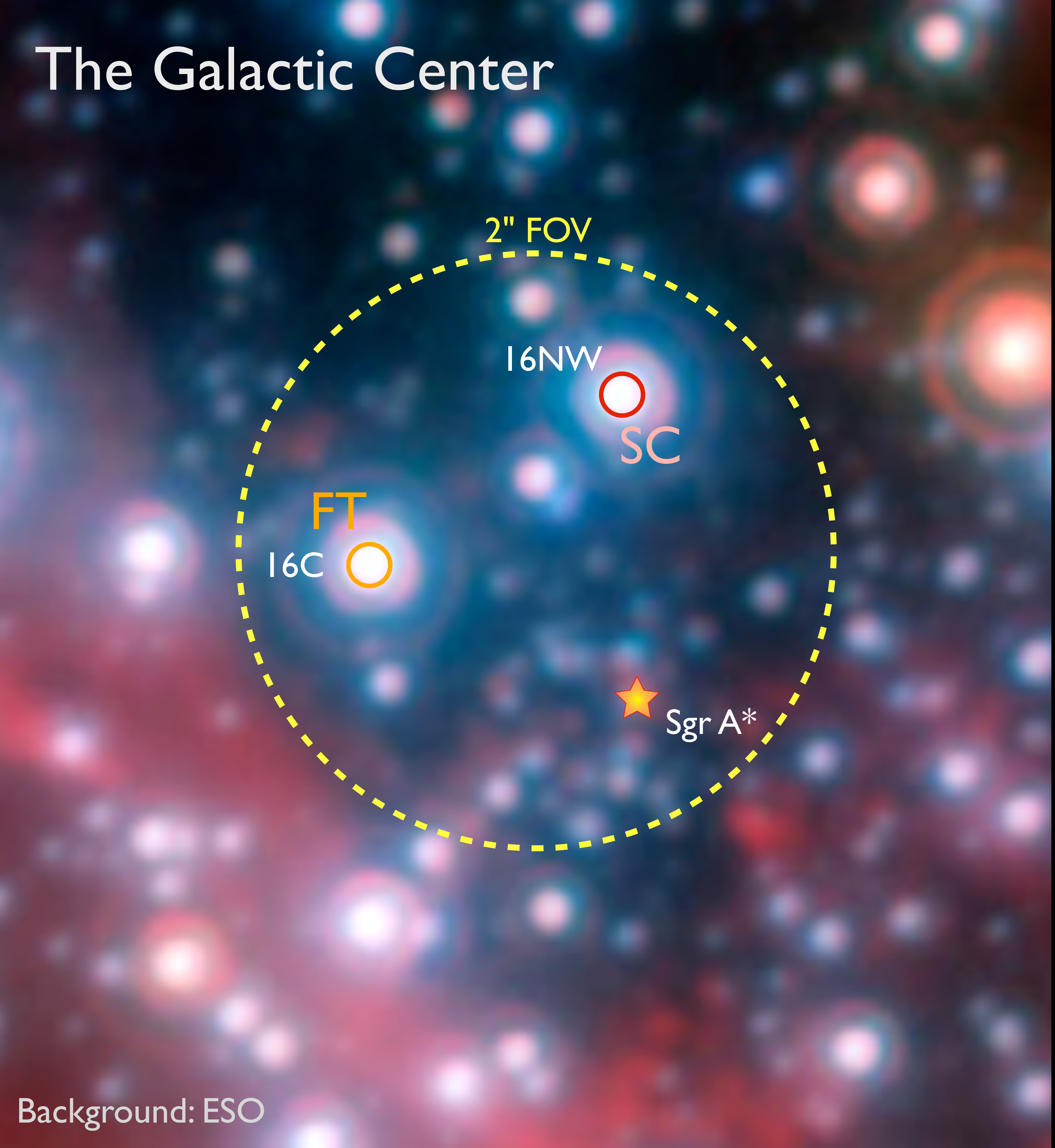

The Galactic Center
IRS 7
AO ref.
1"
Background: ESO

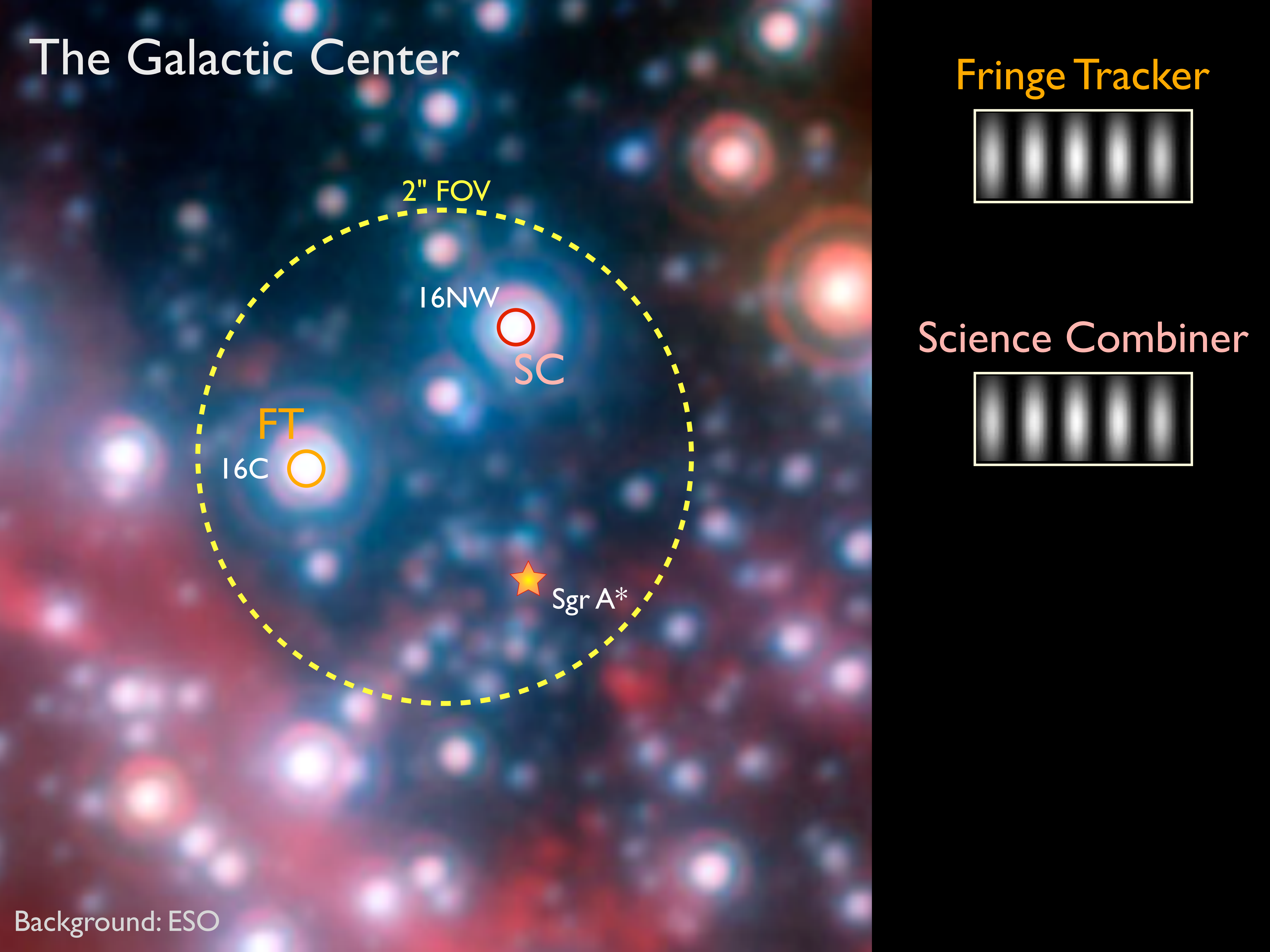

The Galactic Center
IRS 7
AO ref.
Interferometric FOV
1"
Background: ESO

The Galactic Center



Background: ESO


The Galactic Center
2" FOV
16NW
SC
FT
16C
Sgr A*
Background: ESO


The Galactic Center
2" FOV
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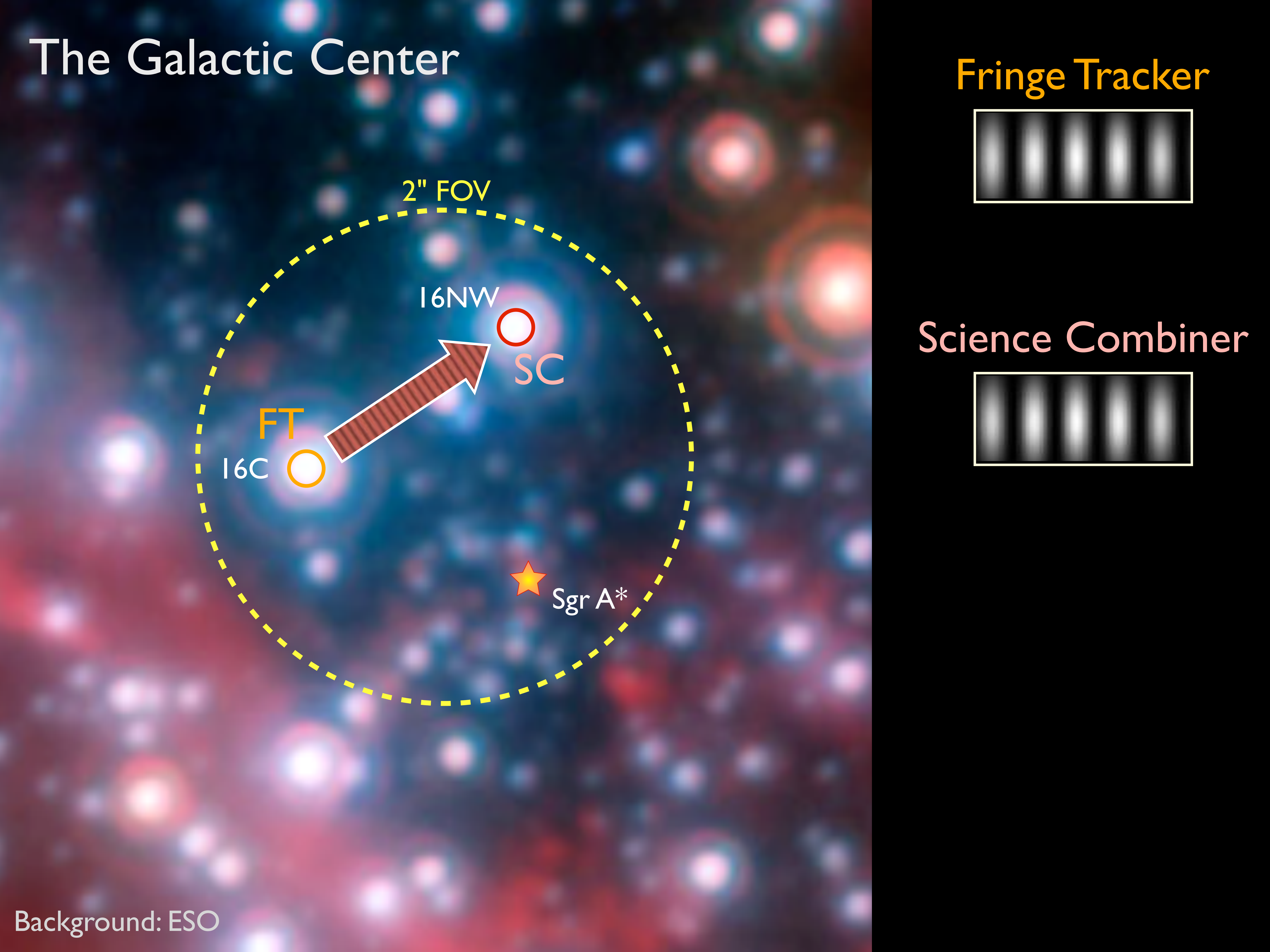
Background: ESO
Fringe Tracker
Science Combiner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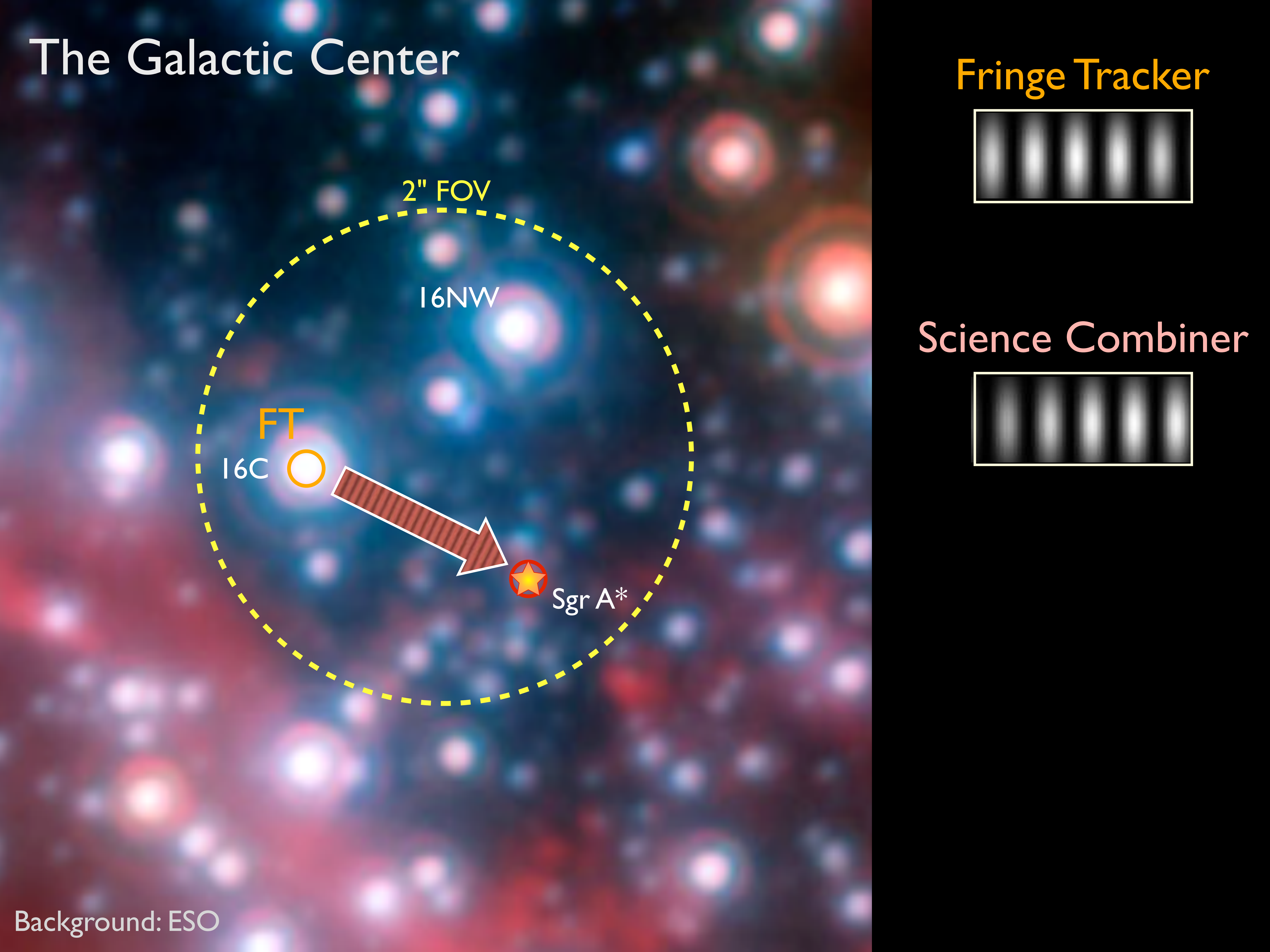
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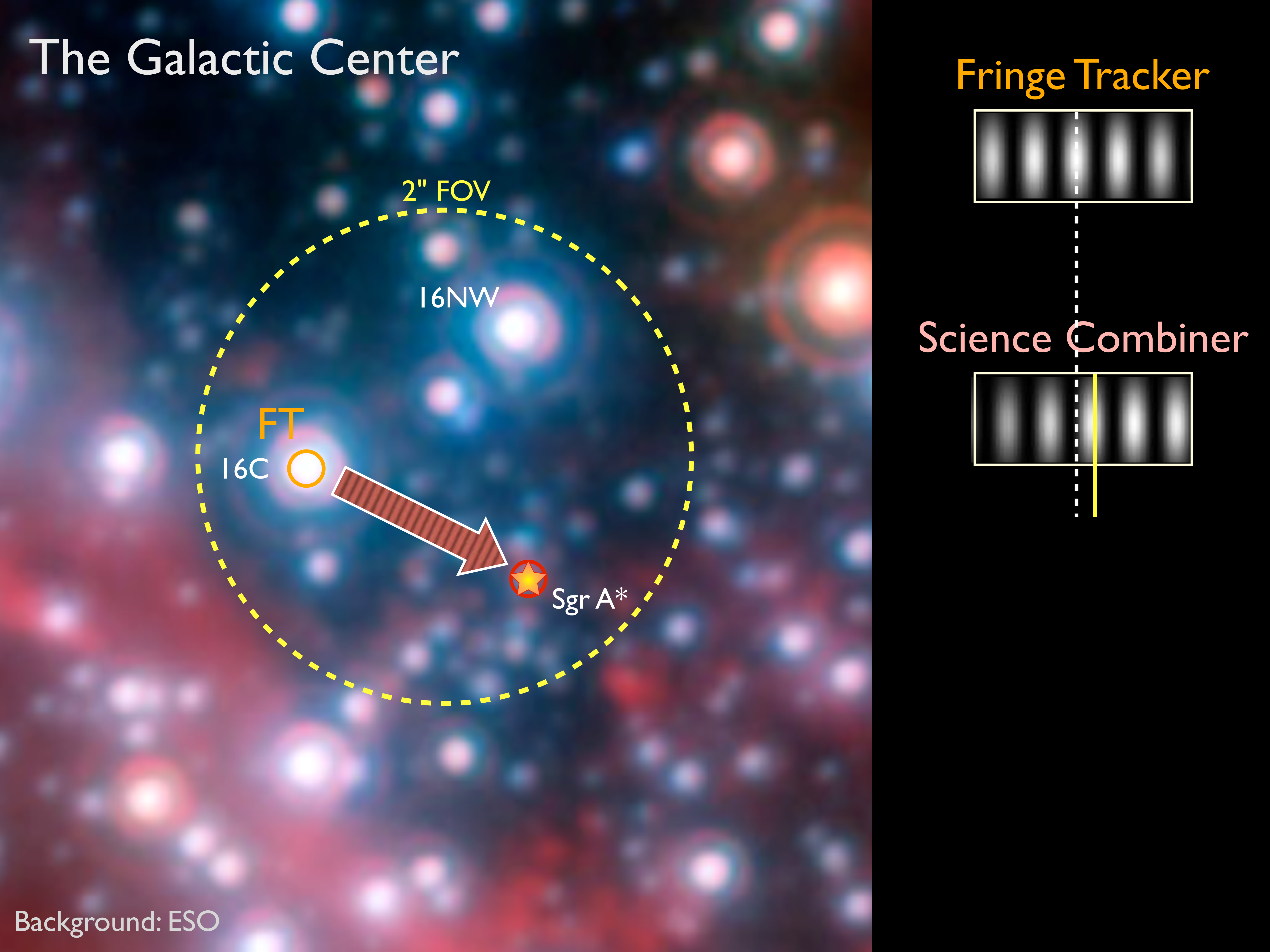
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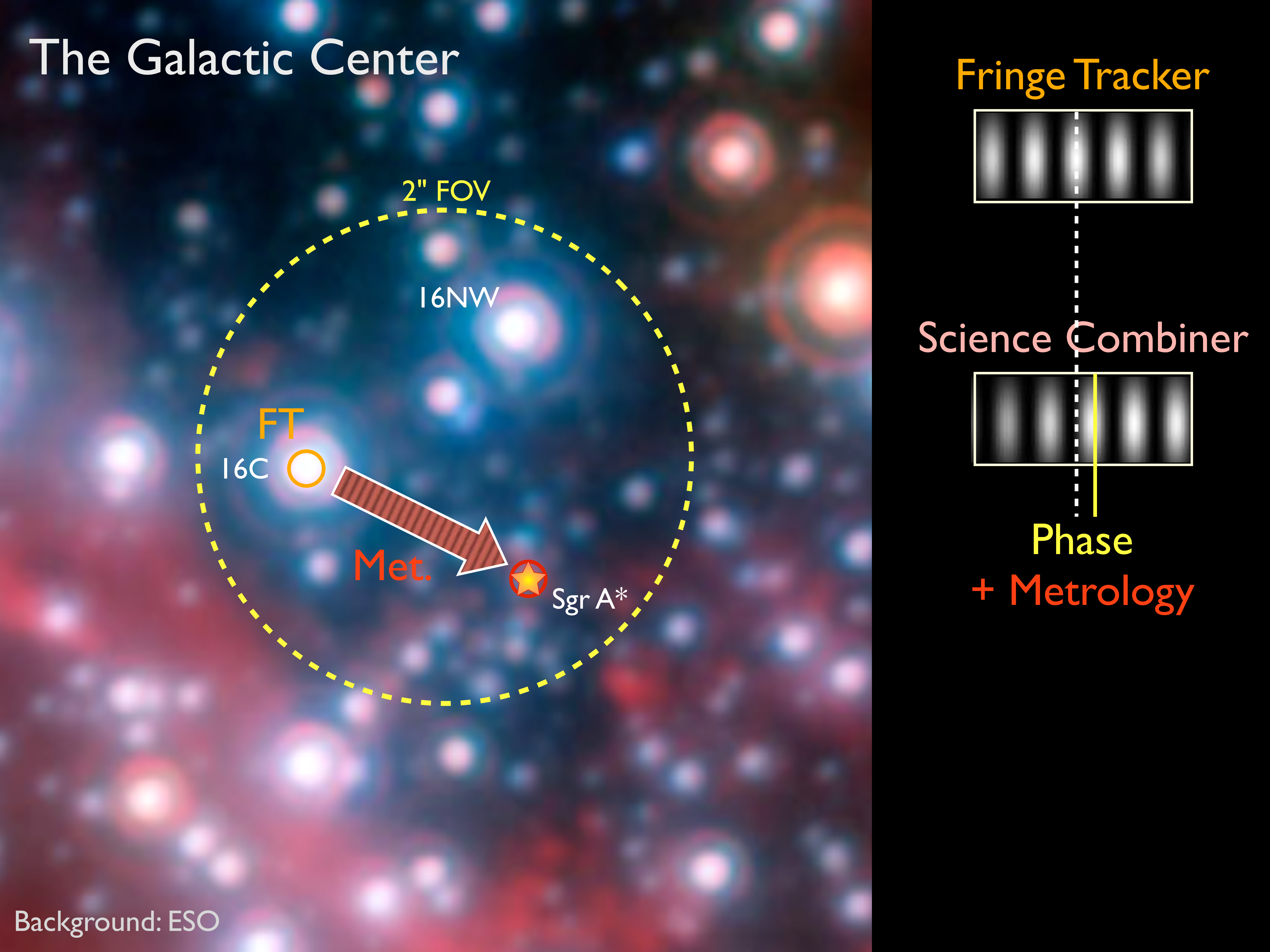
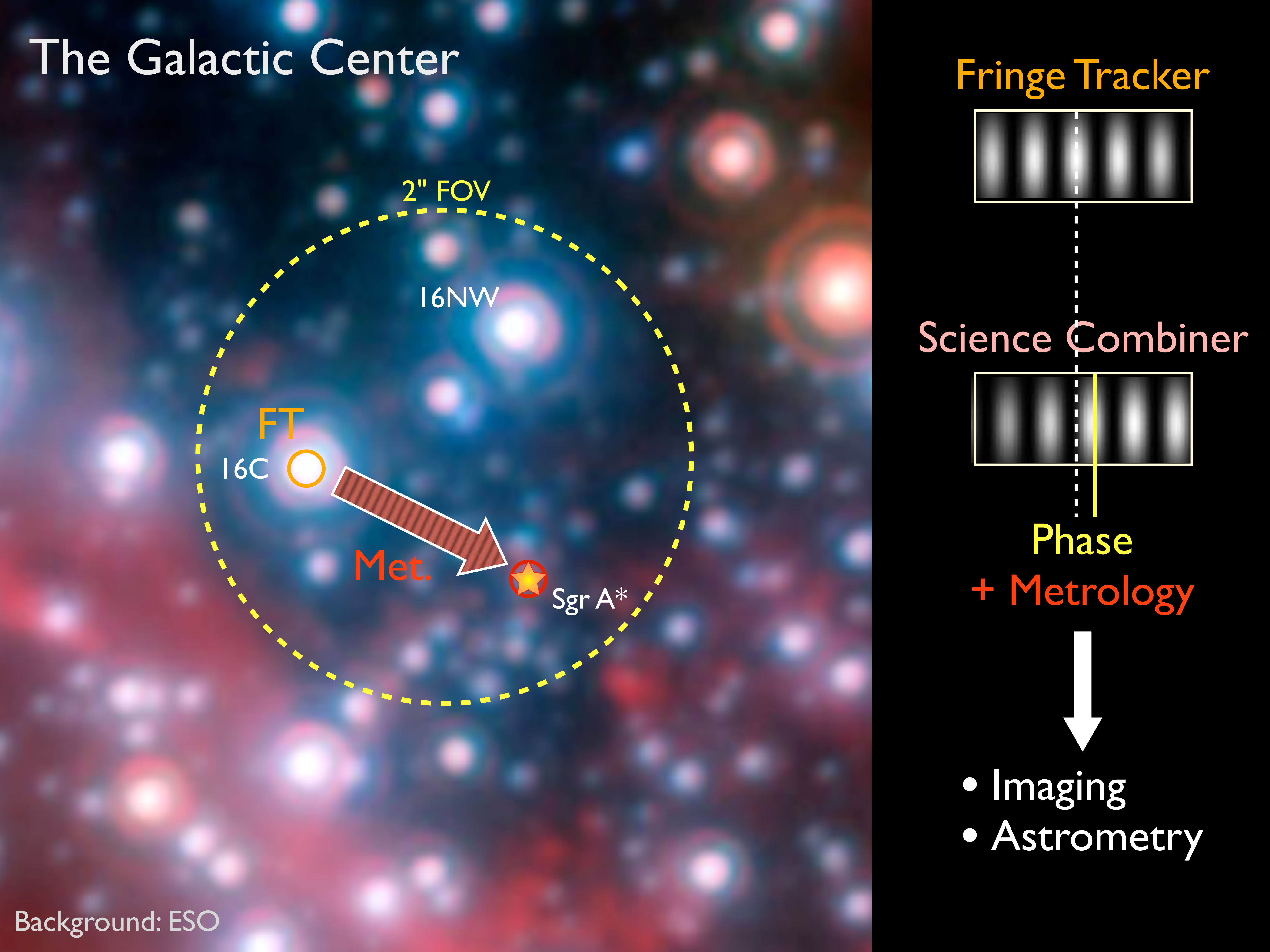

The Galactic Center
2" FOV
16NW
FT
16C
Met.
Sgr A*
Background: ESO
Fringe Tracker
Science Combiner
Phase
+ Metrology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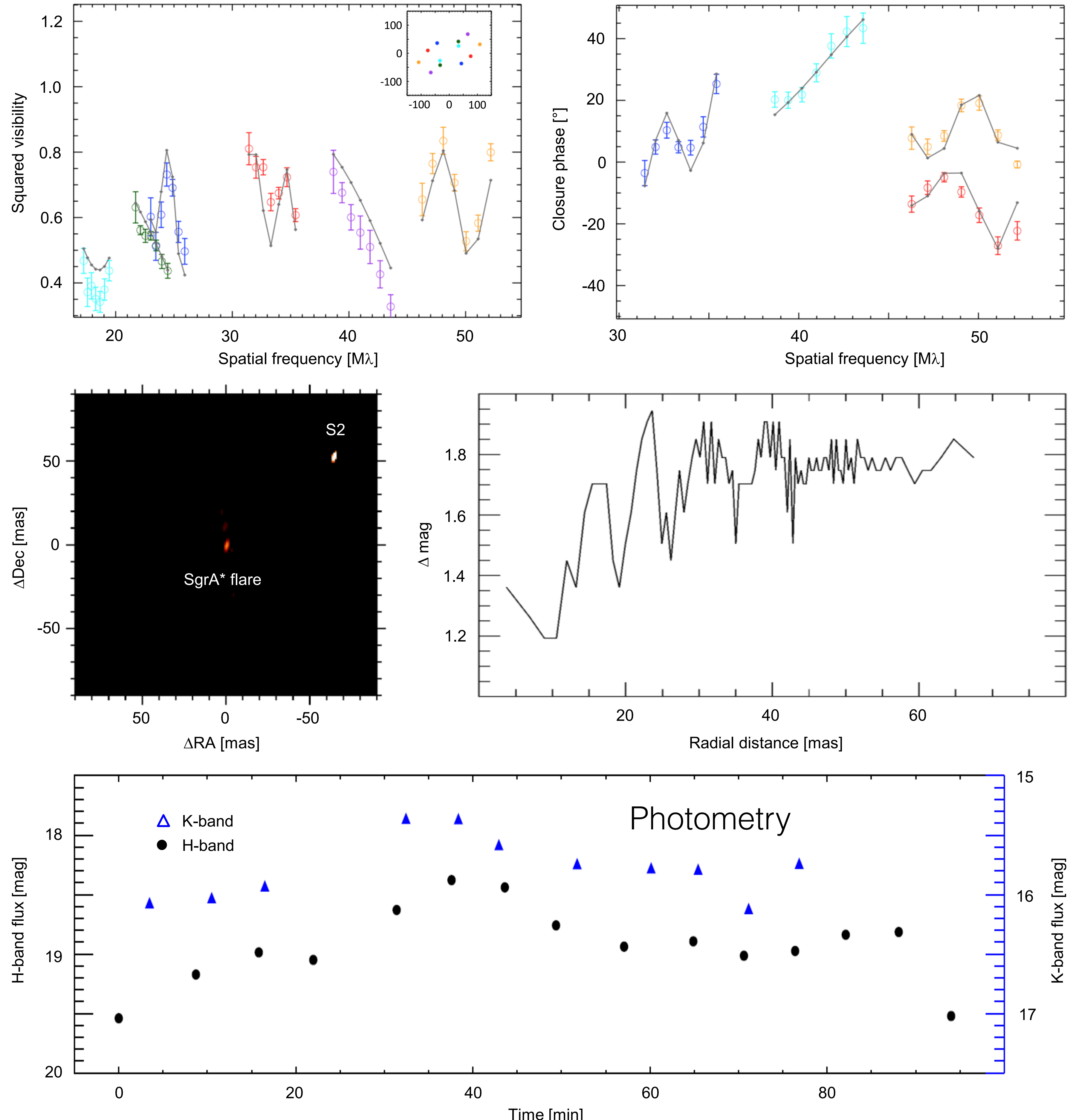
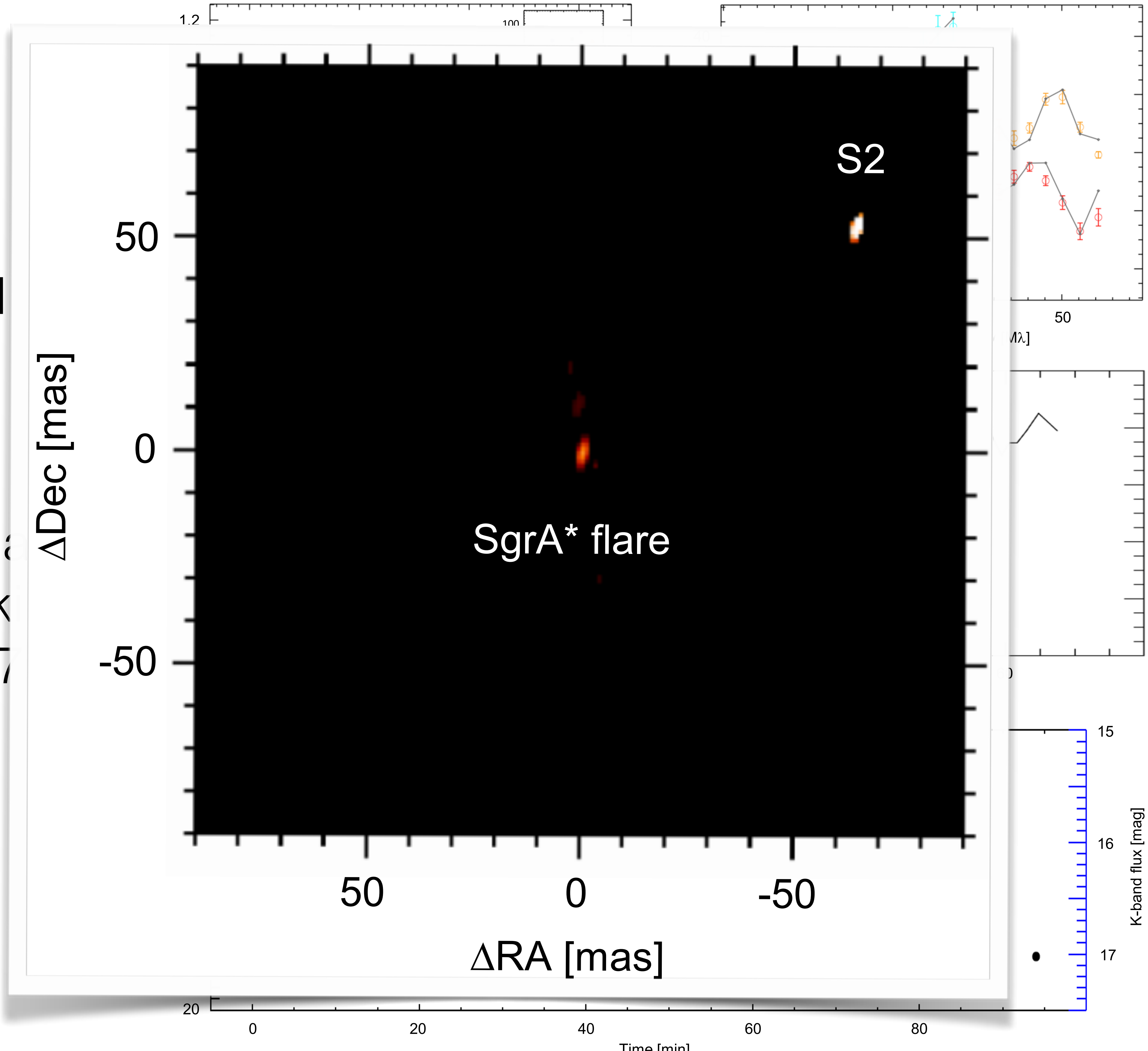
Background: ESO
Fringe Tracker
Science Combiner
Phase
+ Metrology
• Imaging
• Astrometry

Single field spectro-imaging/ astrometry with external fringe tracking on GCIRS 7



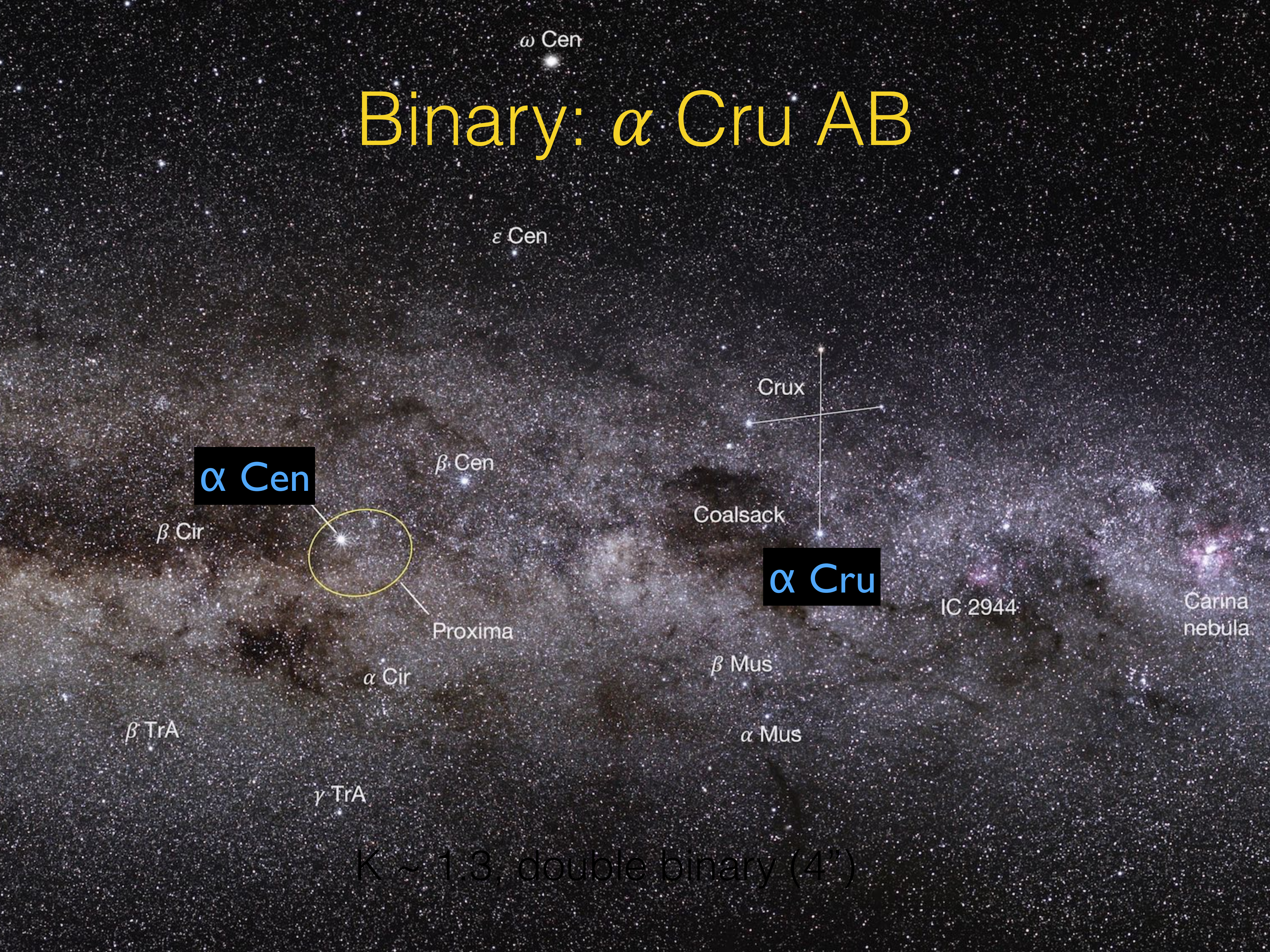
GRAVITY Collaboration 2017, A&A, 602, A94

Single field
spectro-
imaging/
astrometry
with externa
fringe track
on GCIRS 7



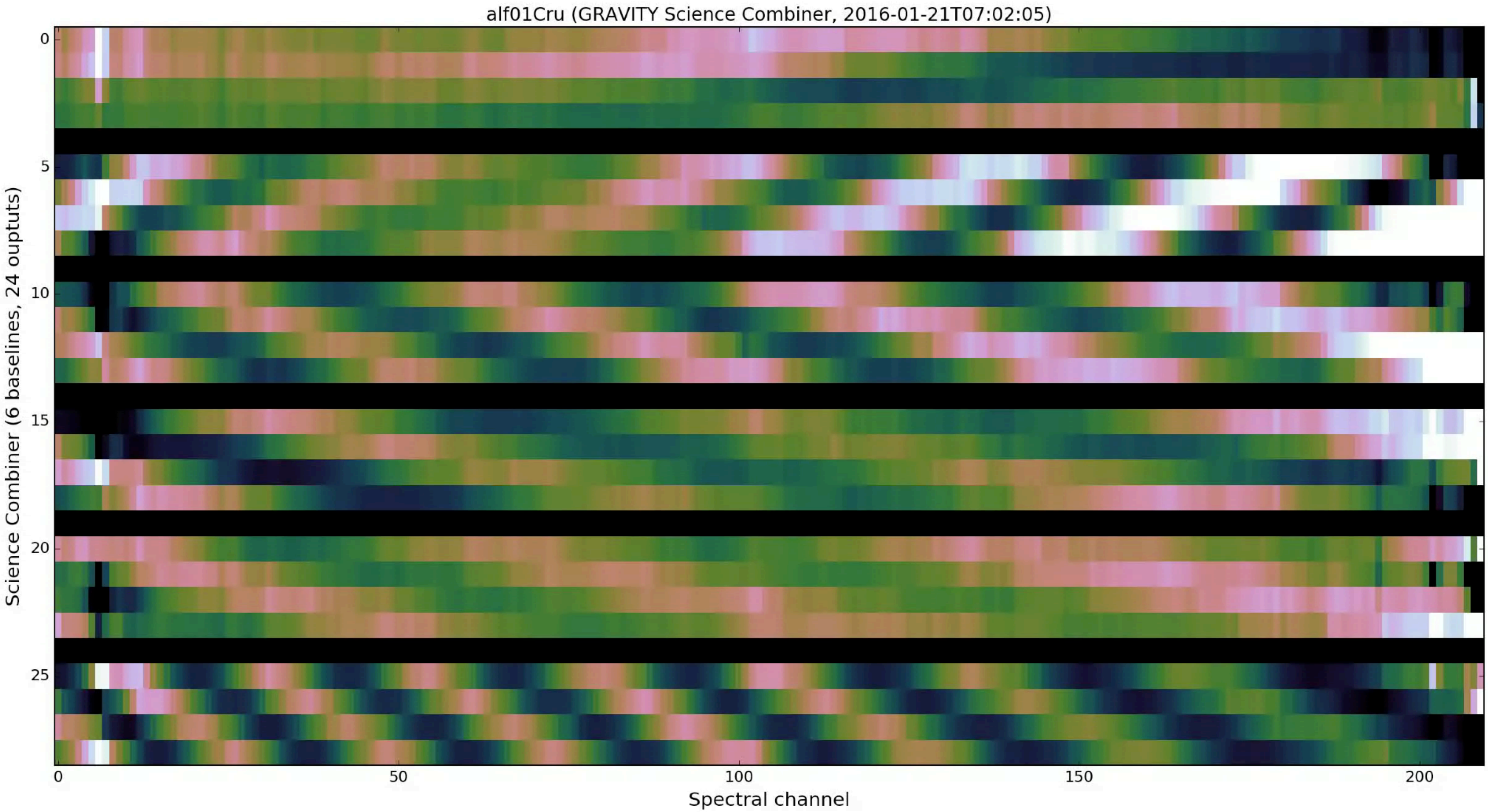
GRAVITY Collaboration 2017, A&A, 602, A94

Binary: α Cru AB

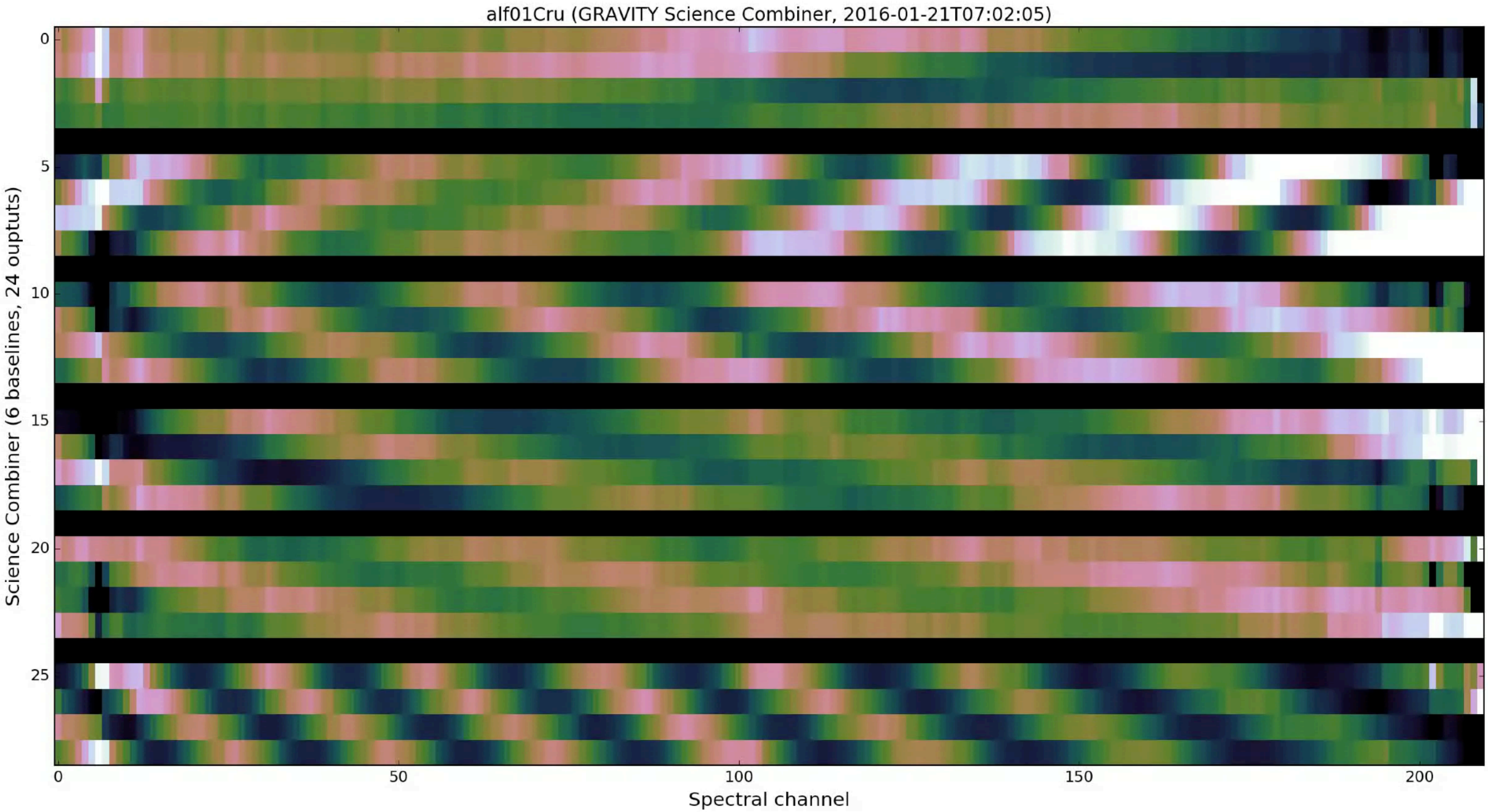


K ~ 1.3, double binary (4'')

Science combiner fringes

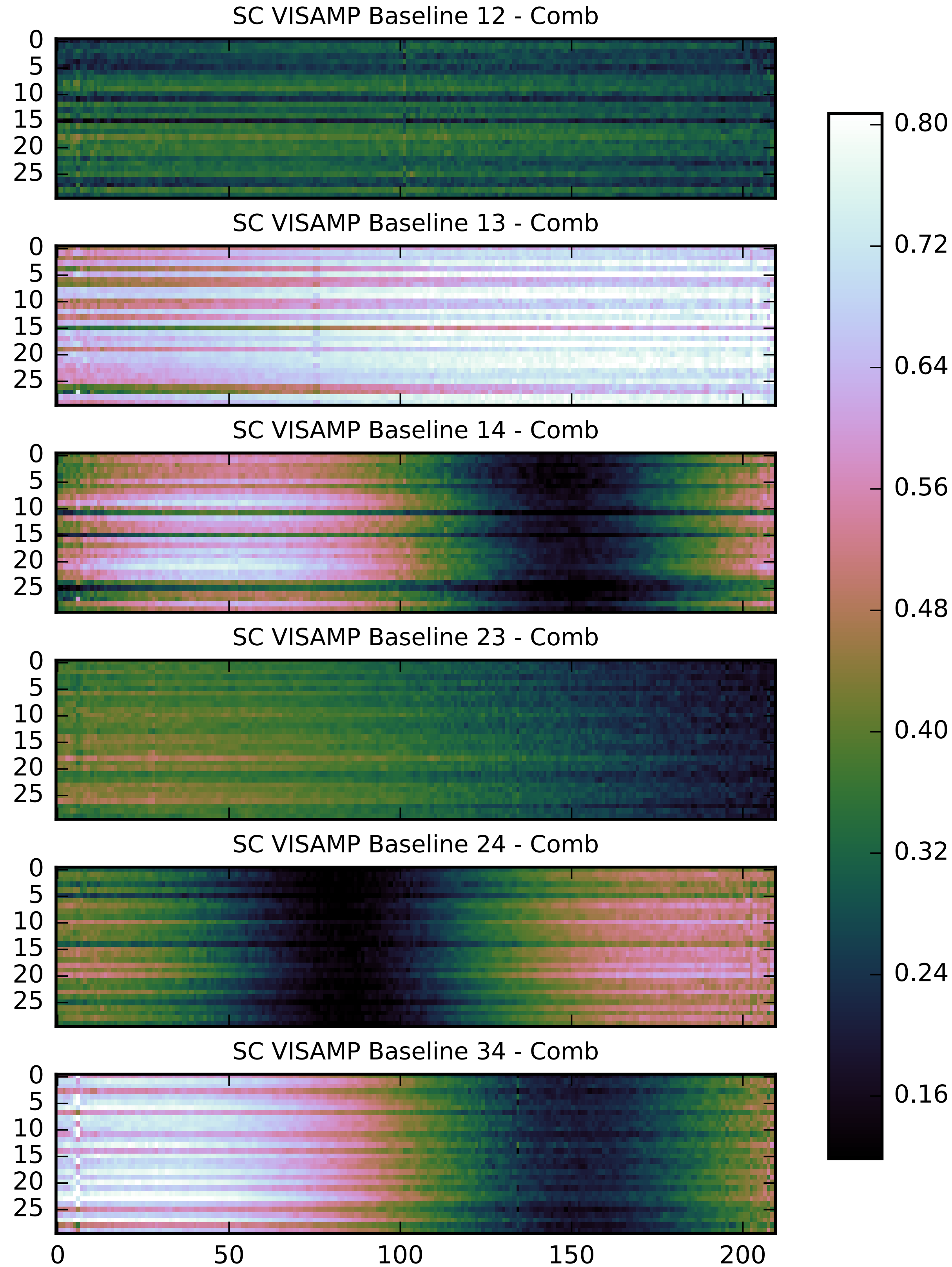


Science combiner fringes



SC visibility amplitude waterfall view (VISAMP SC)

Wavelength channel number in horizontal axis, number of frame in sequence in vertical axis.



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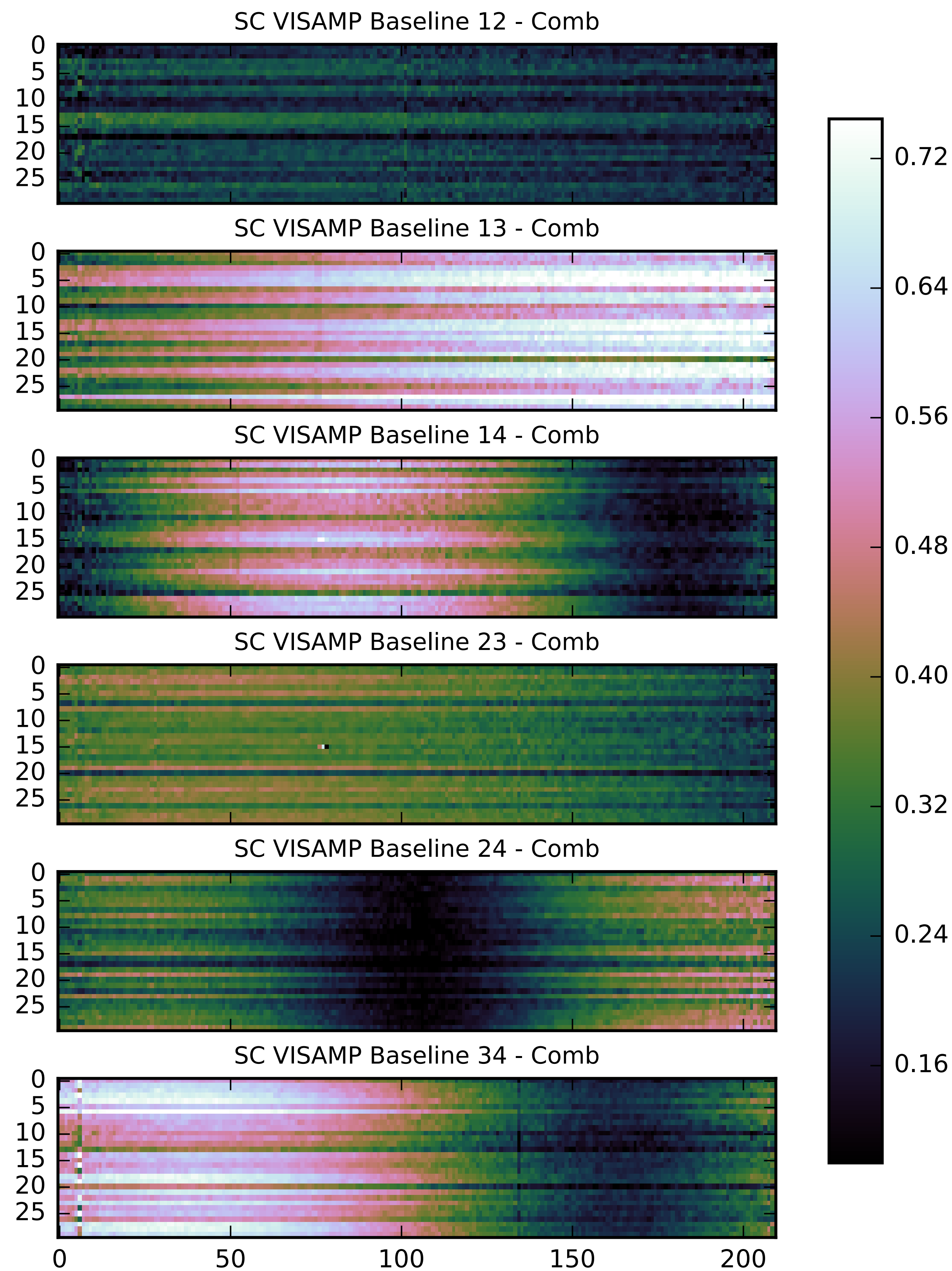
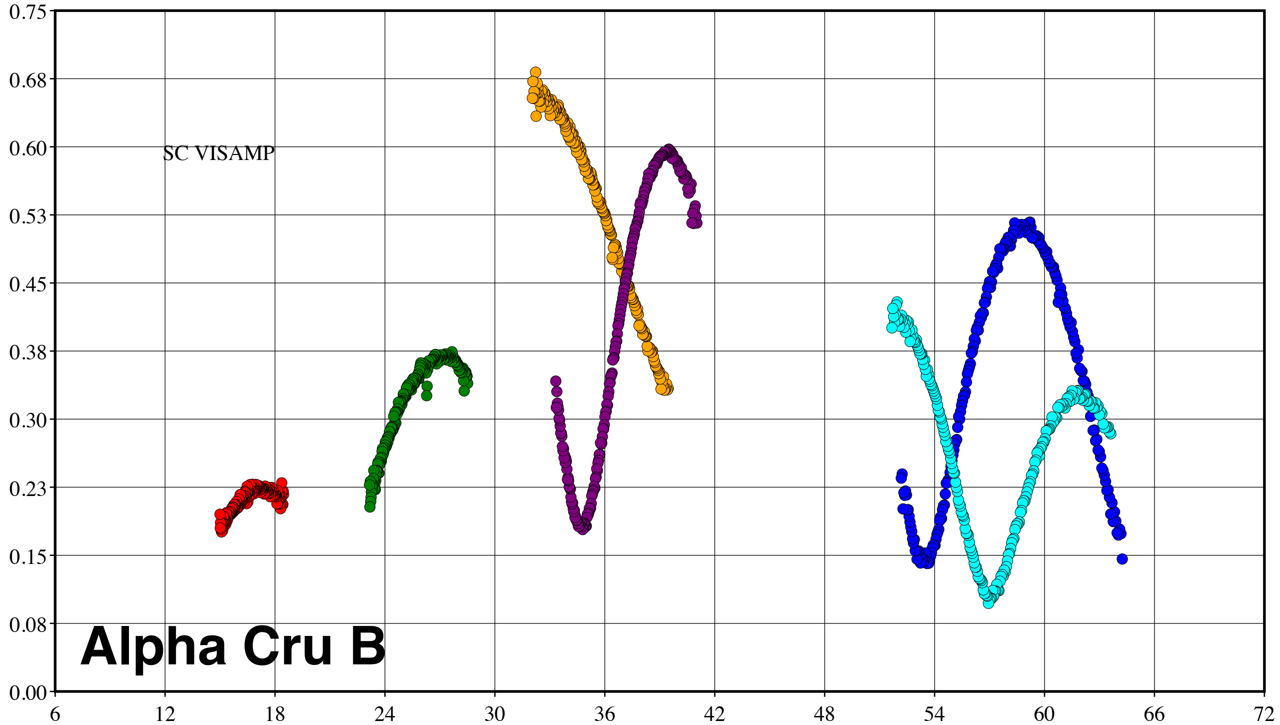


SC visibility amp. vs. spatial frequency (VISAMP SC)

Visibility vs. spatial frequency (megalambda).



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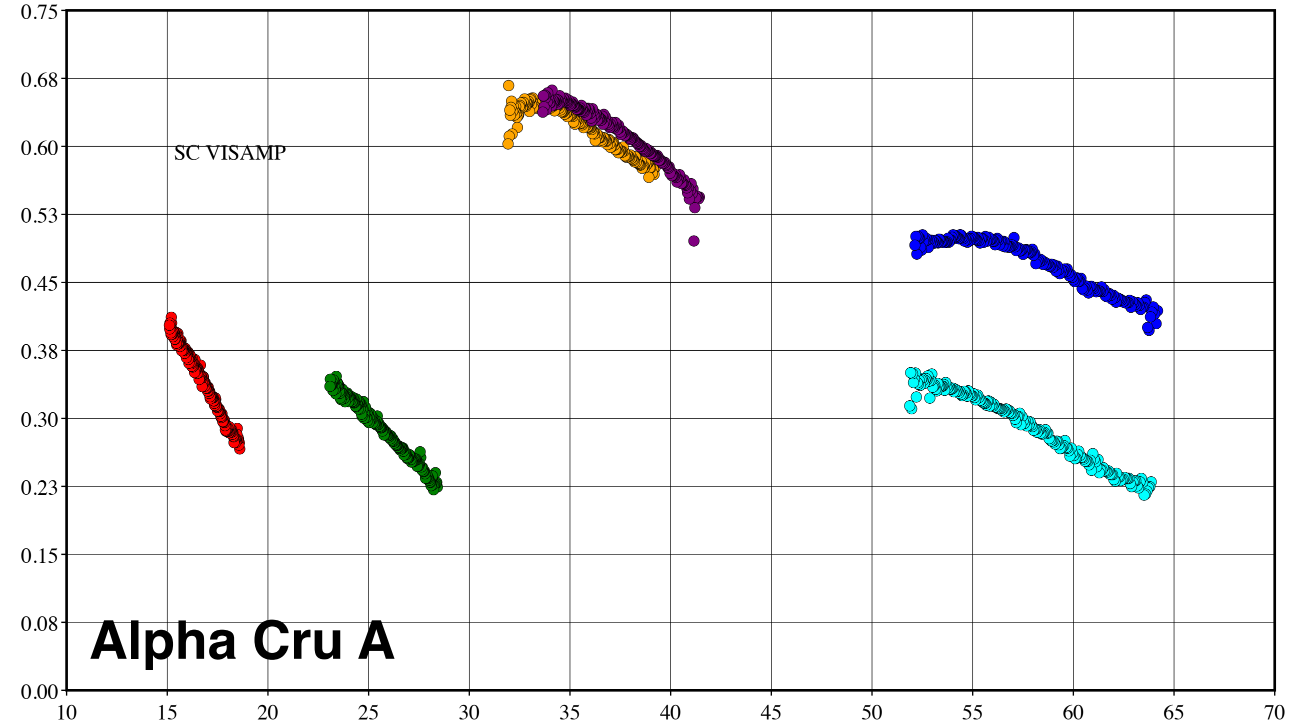
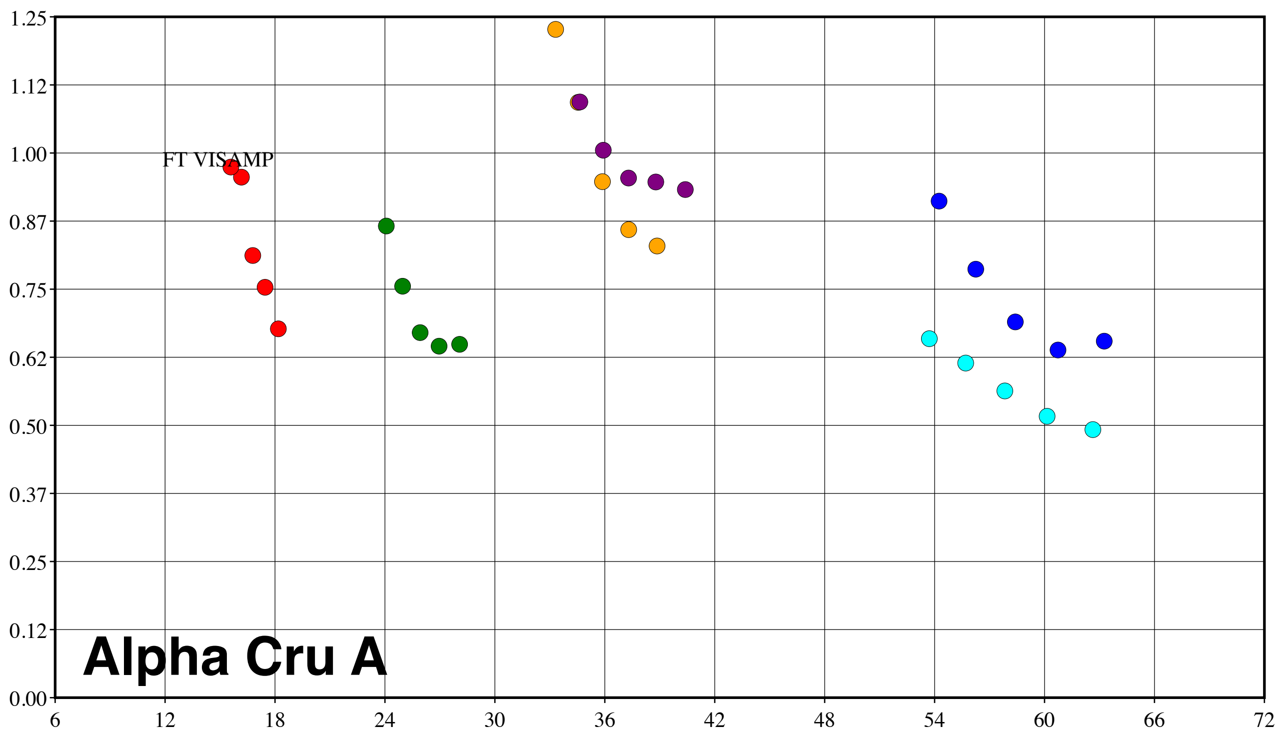


FT visibility amp. vs. spatial frequency (VISAMP FT)

Visibility vs. spatial frequency (megalambda).



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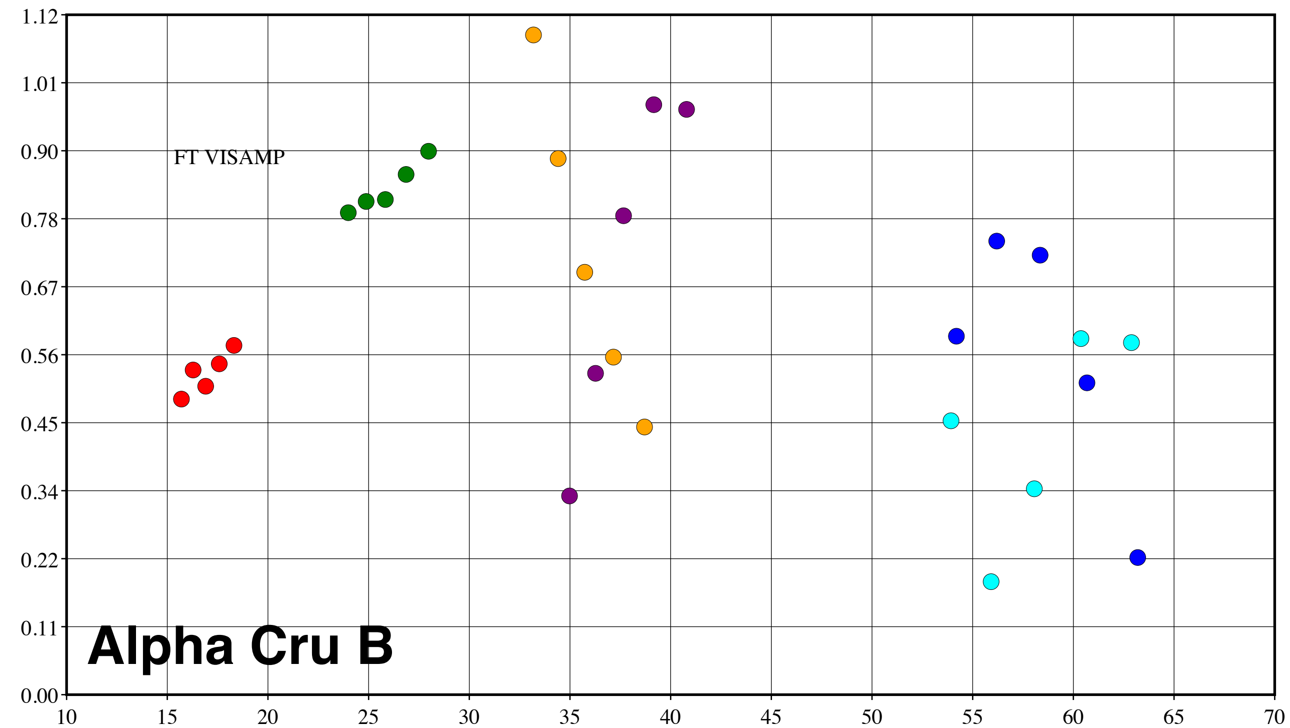

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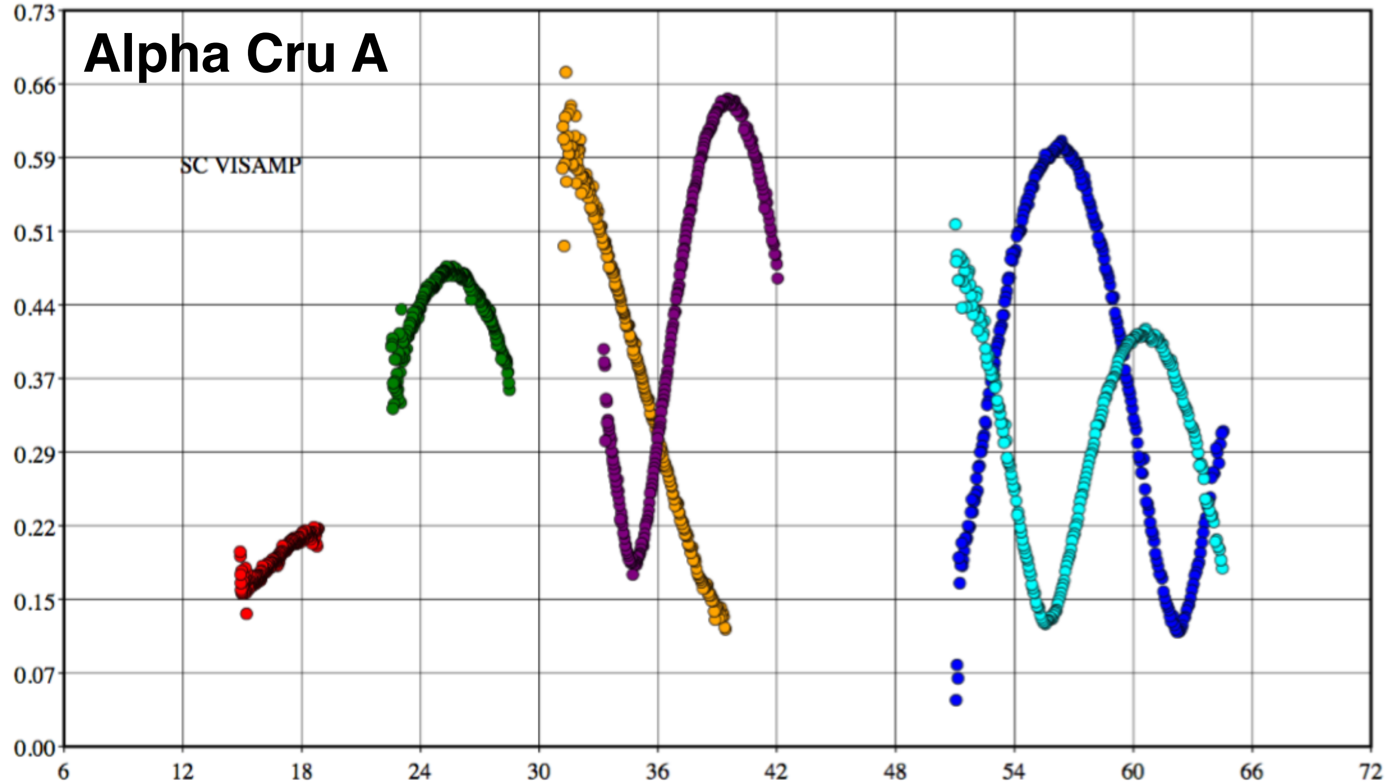
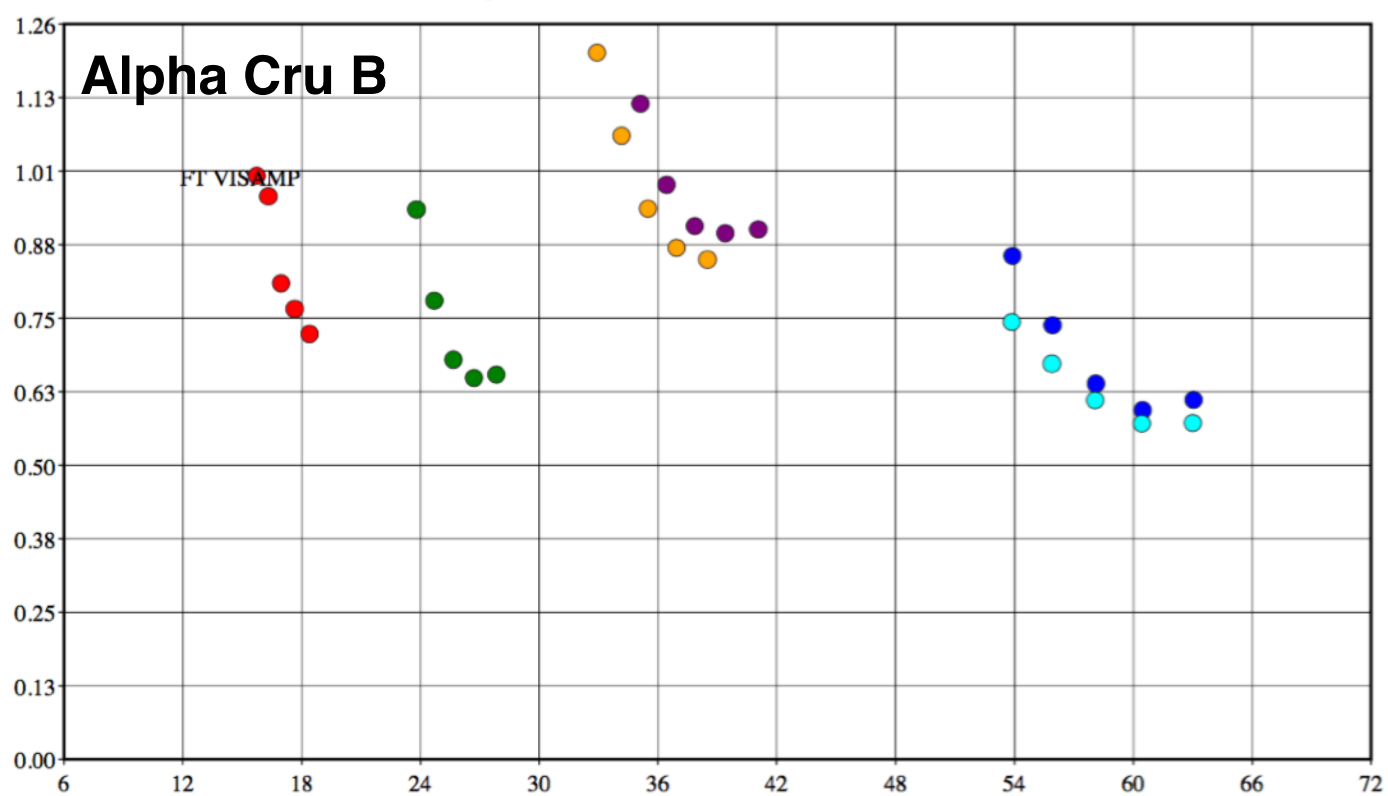


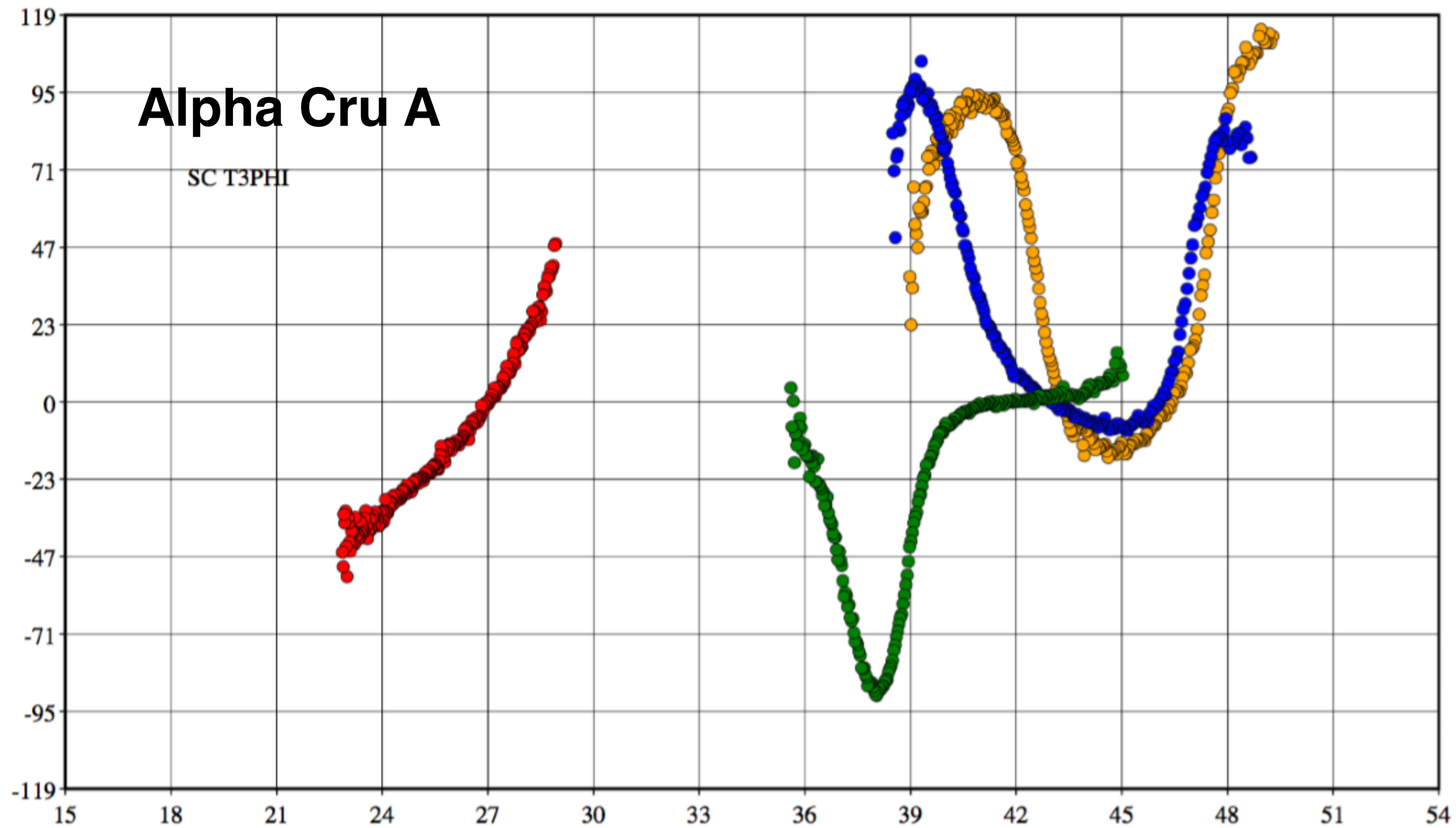
FT visibility amp. vs. spatial frequency (VISAMP FT)

Visibility vs. spatial frequency (megalambda).



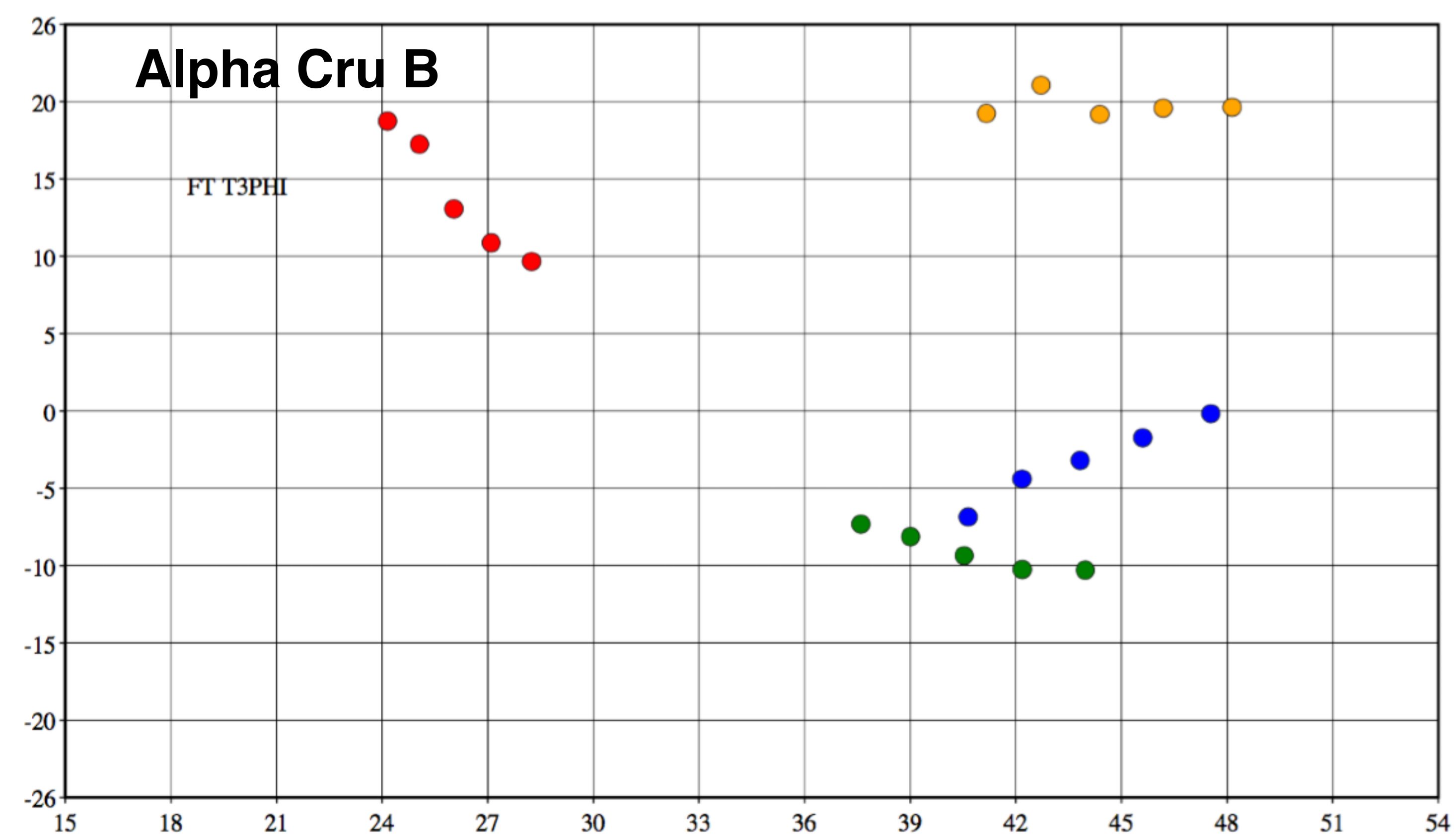
SC closure phase vs. spatial frequency (T3PHI SC)

Closure phase (degrees) vs. mean spatial frequency over triangle (megalambda).

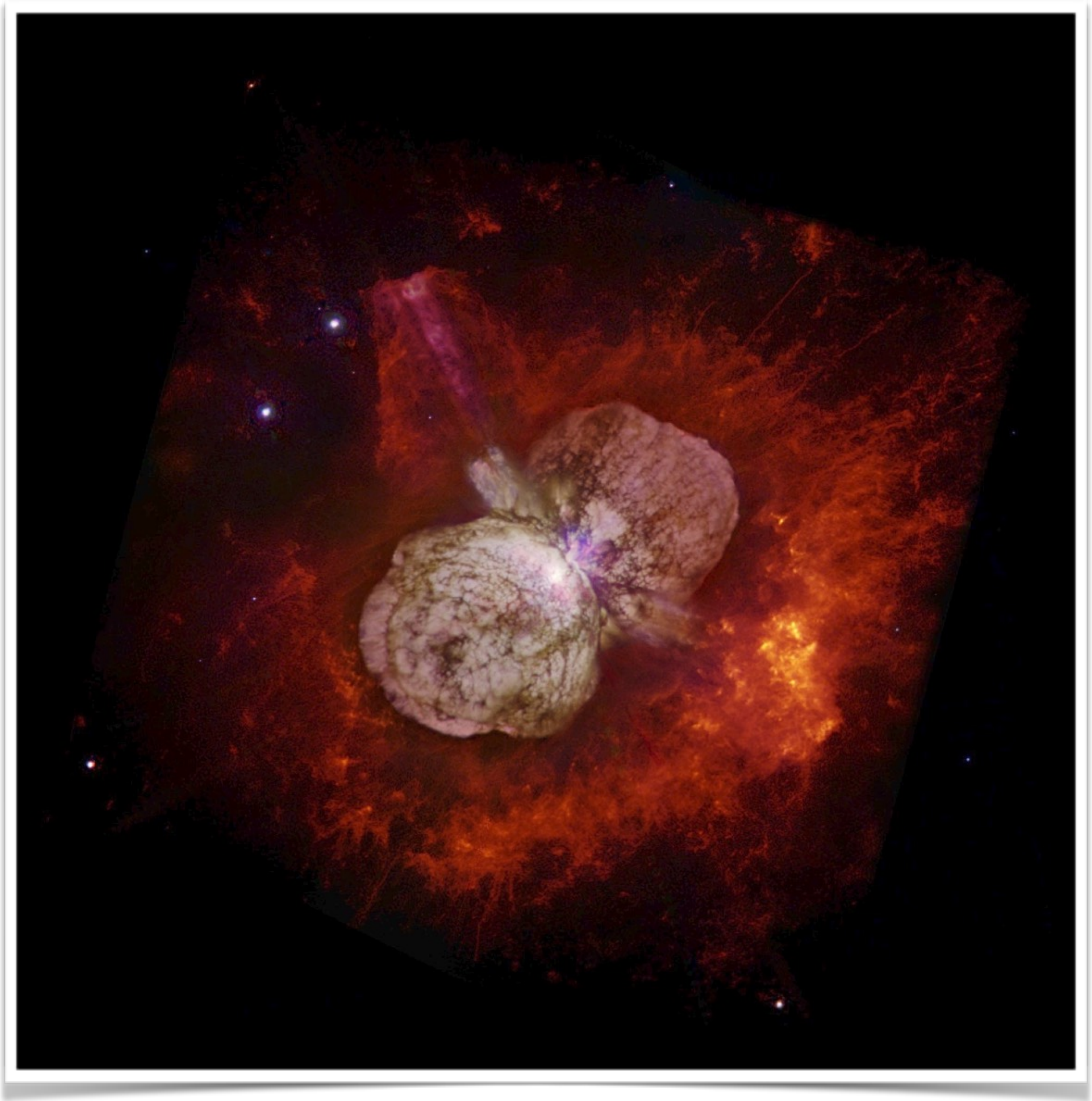


FT closure phase vs. spatial frequency (T3PHI FT)

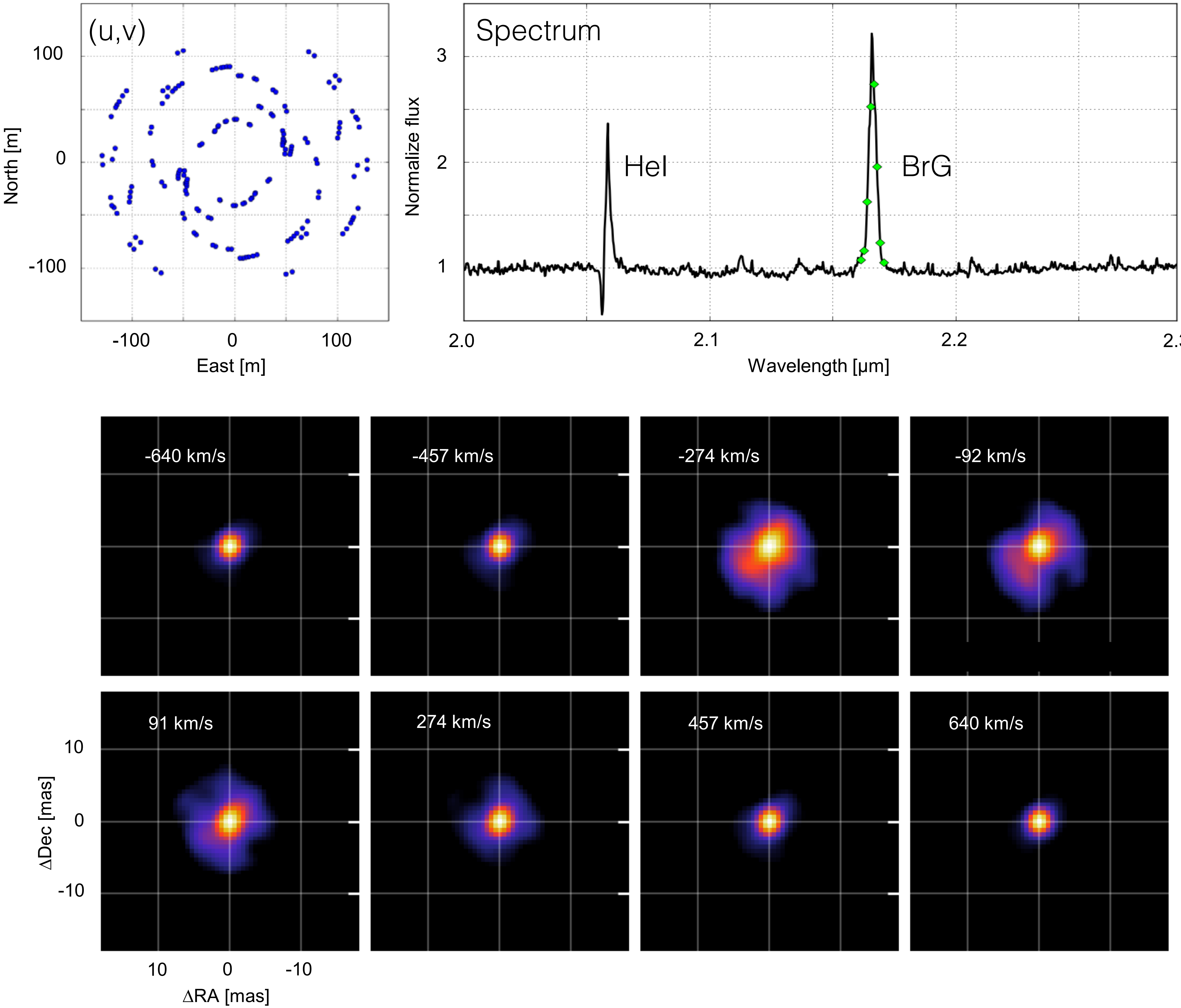
Closure phase (degrees) vs. mean spatial frequency over triangle (megalambda).



η Carinae

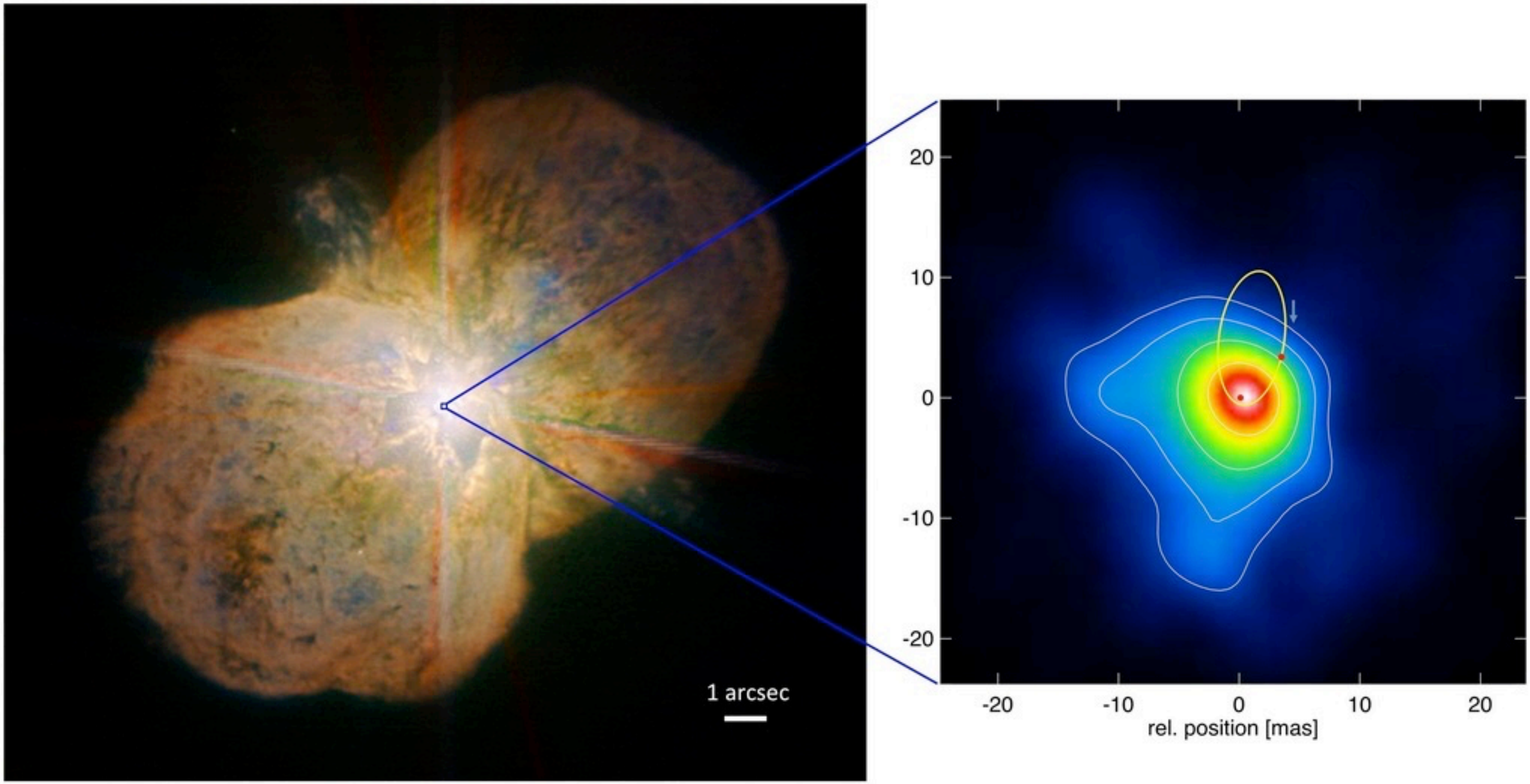


K ~ 1.0 (central source)

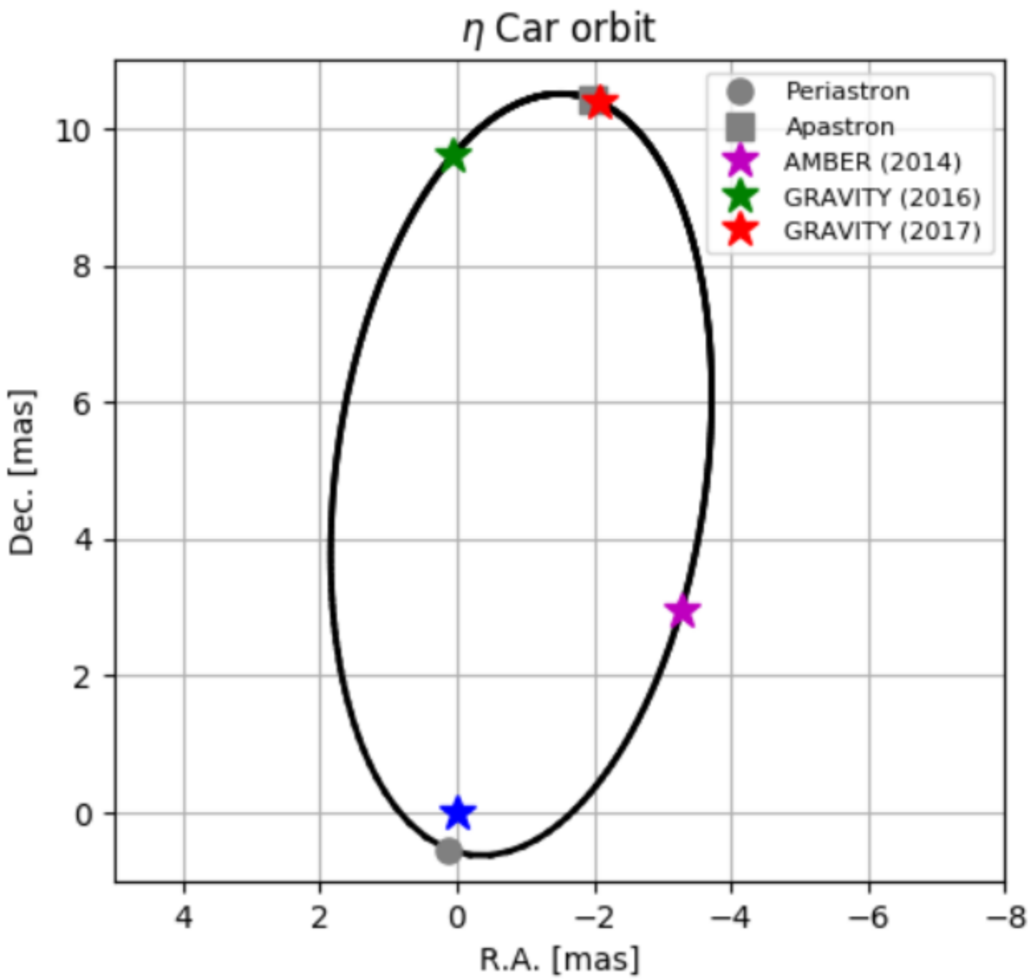


GRAVITY Collaboration 2017, A&A, 602, A94; Sanchez-Bermudez+ in prep.

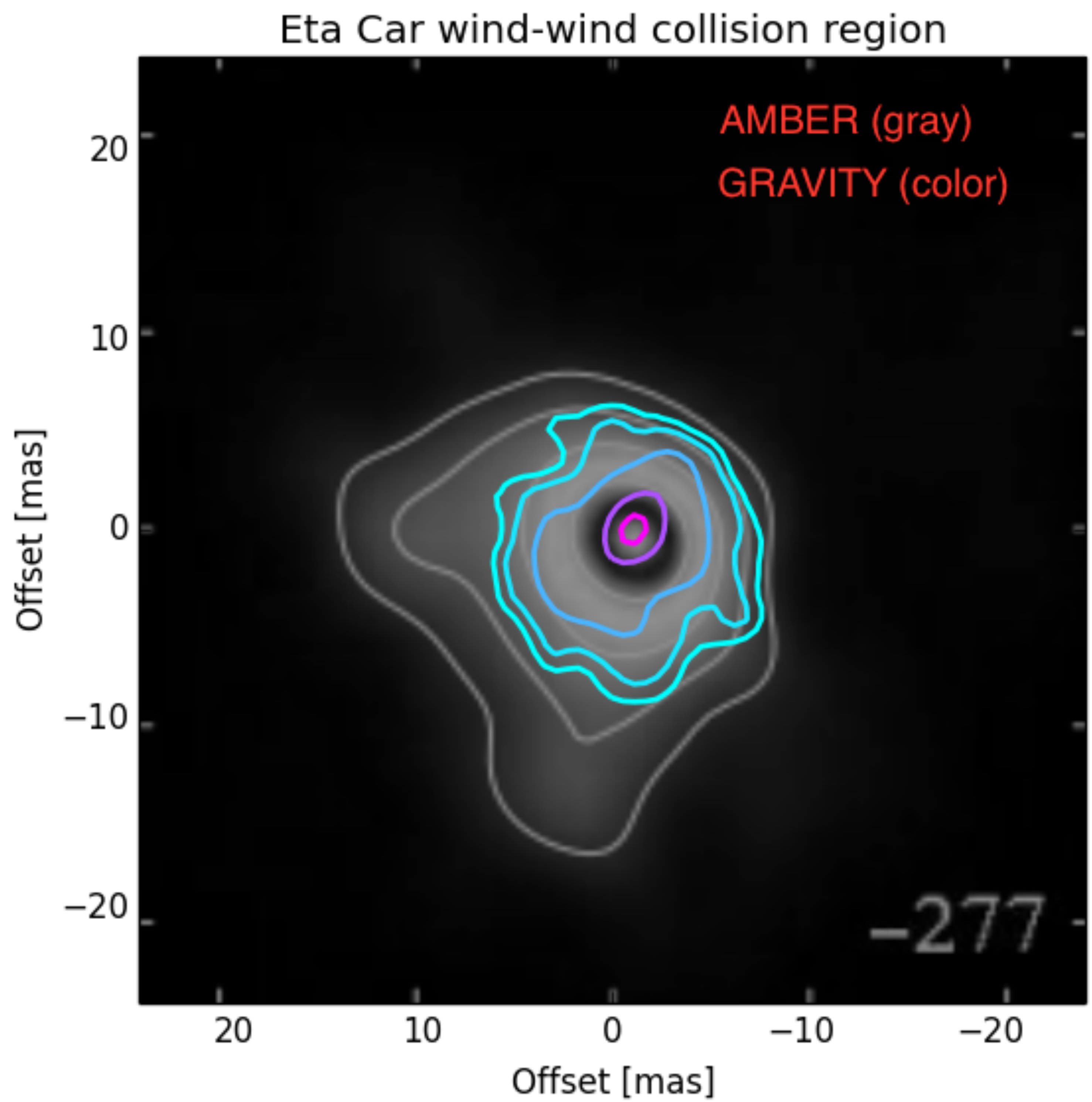
AMBER

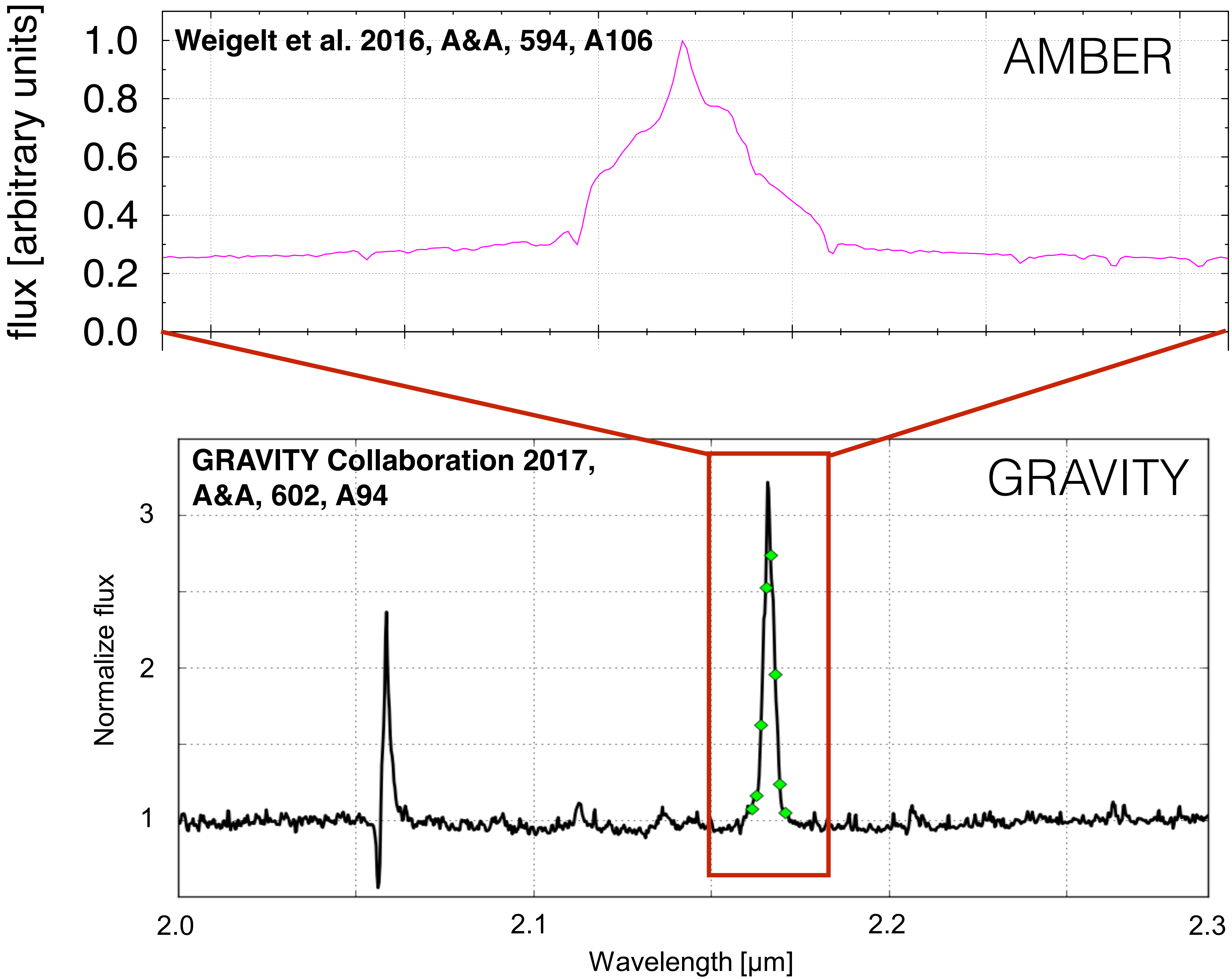


Weigelt et al. 2016, A&A, 594, A106



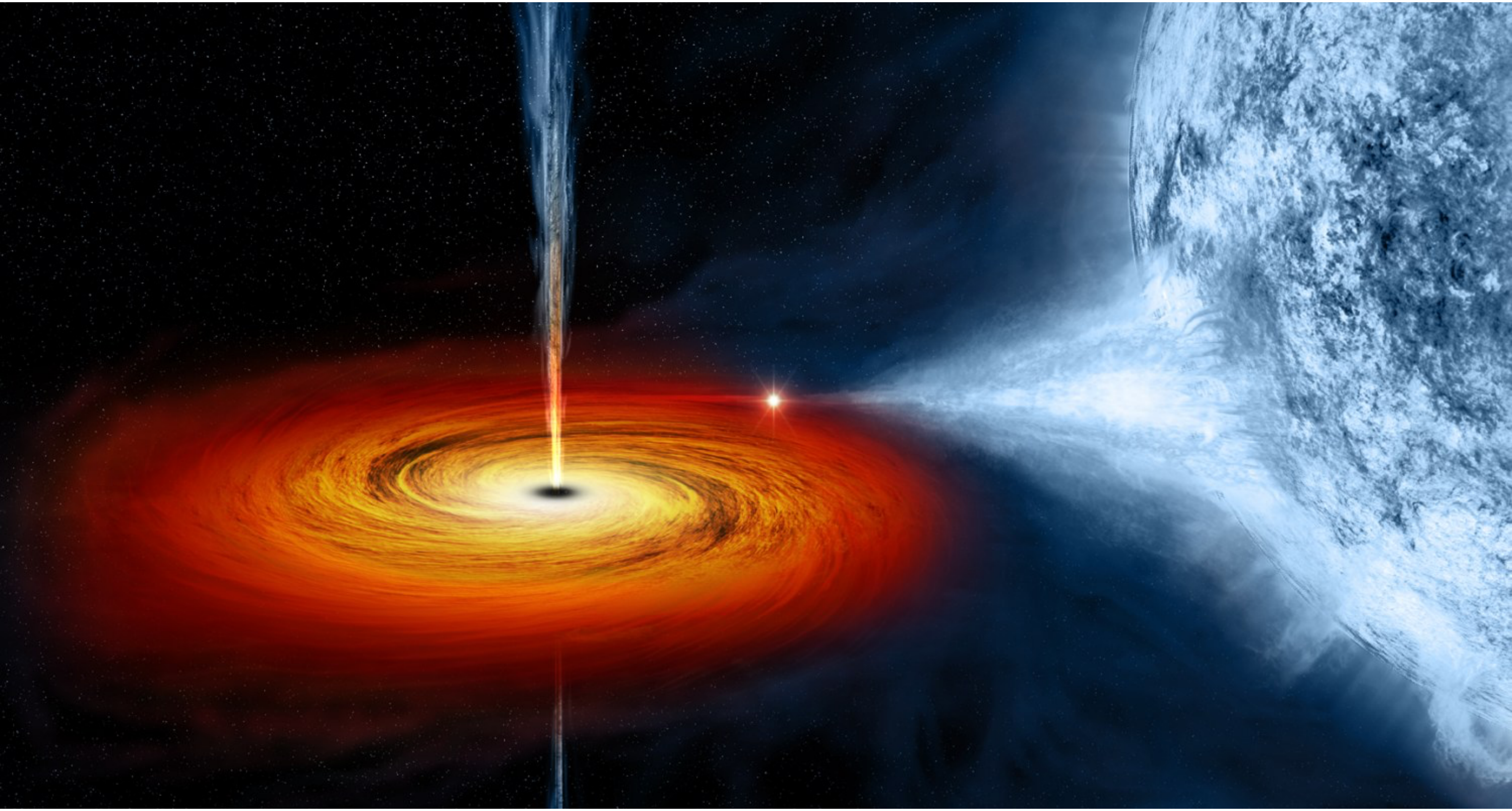
Teodoro+ 2016, ApJ, 819, 131



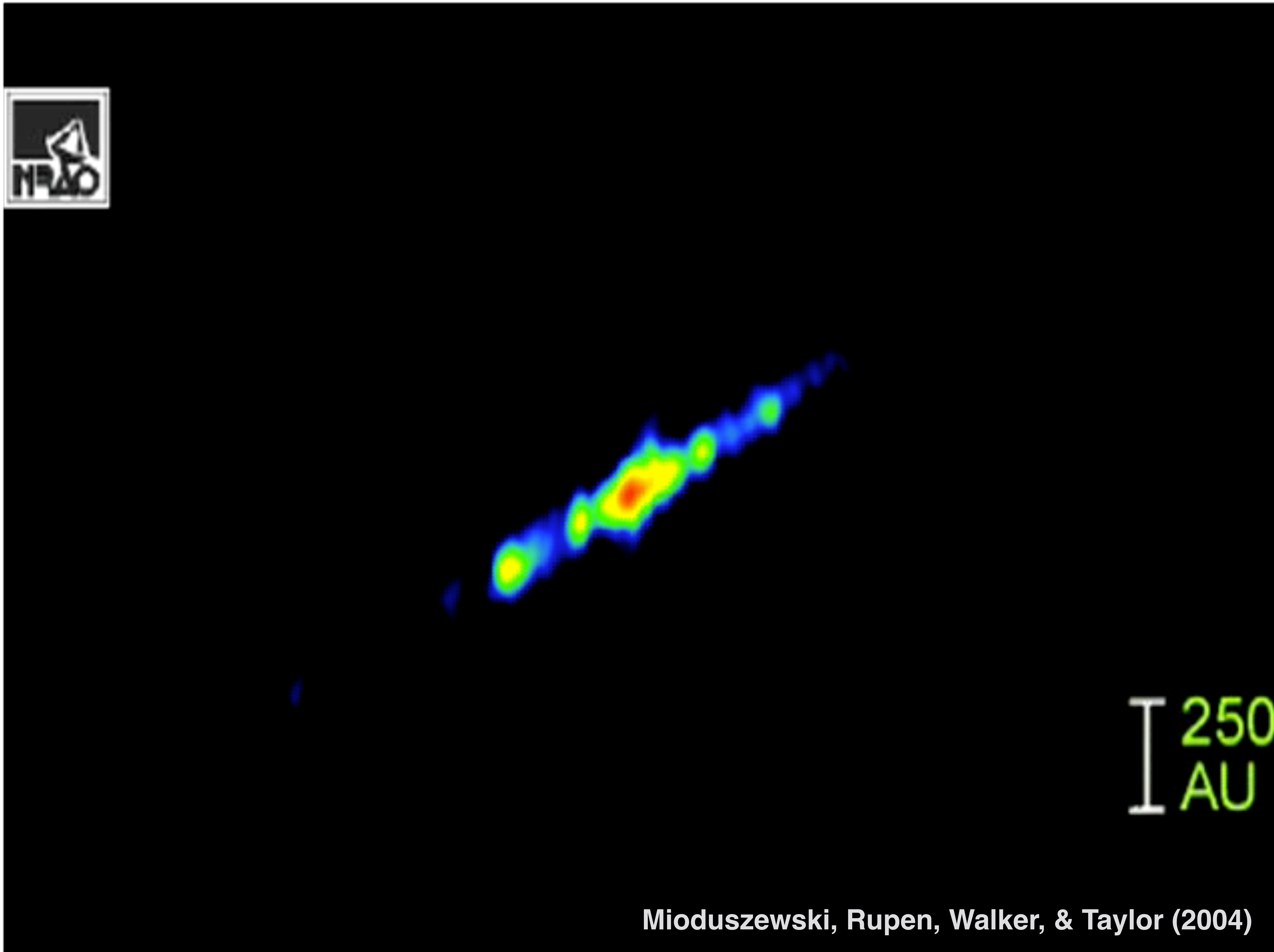


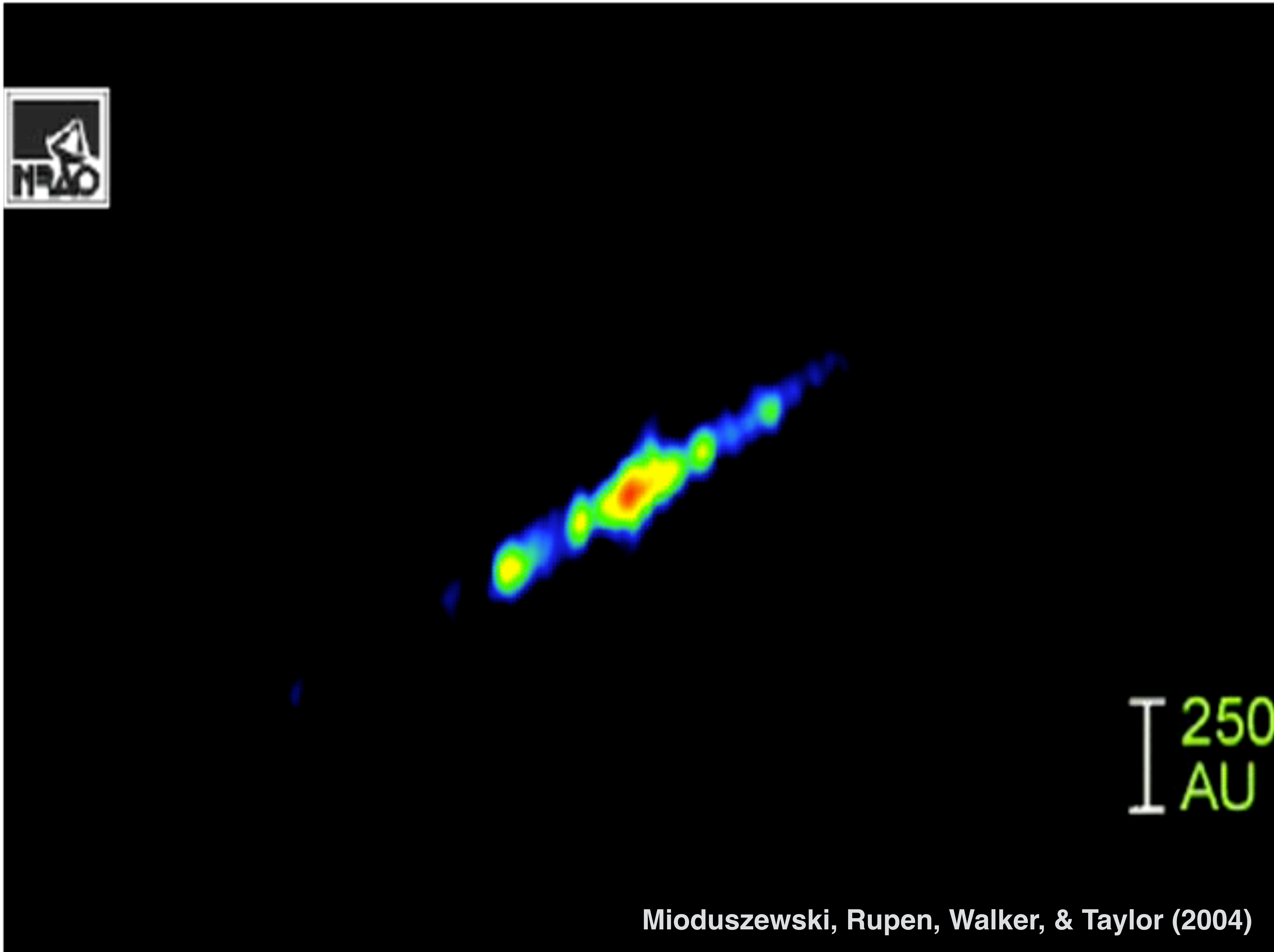
flux [arbitrary units]
1.0
0.8
0.6
0.4
0.2
0.0
Weigelt et al. 2016, A&A, 594, A106
AMBER
GRAVITY Collaboration 2017,
A&A, 602, A94
GRAVITY
Normalize flux
3
2
1
2.0
2.1
2.2
2.3
Wavelength [μm]

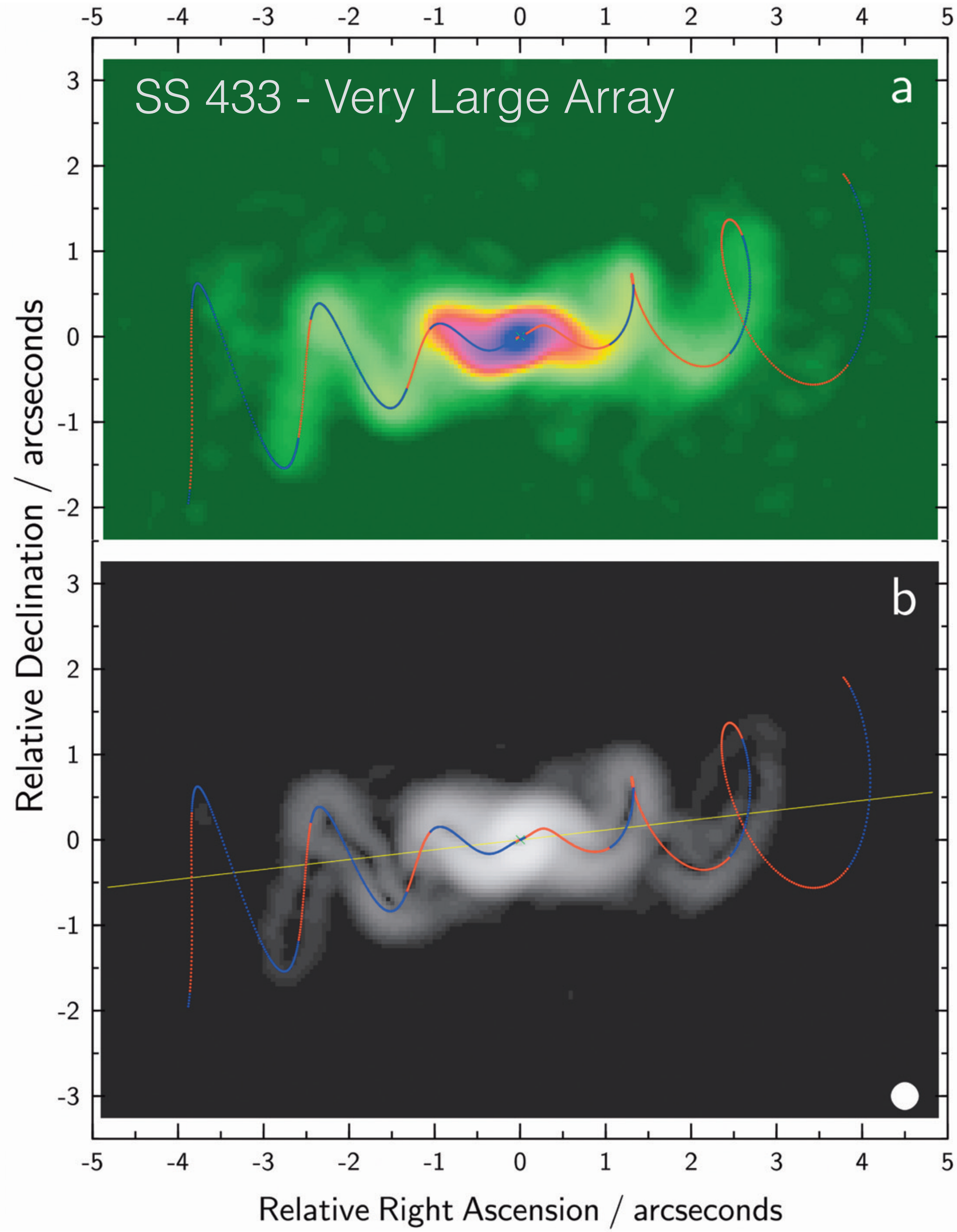
Microquasar SS 433



- Black hole (likely) - blue supergiant high mass X-ray binary (HMXB)


250
AU
Mioduszewski, Rupen, Walker, & Taylor (2004)


NRAO
250
AU
Mioduszewski, Rupen, Walker, & Taylor (2004)

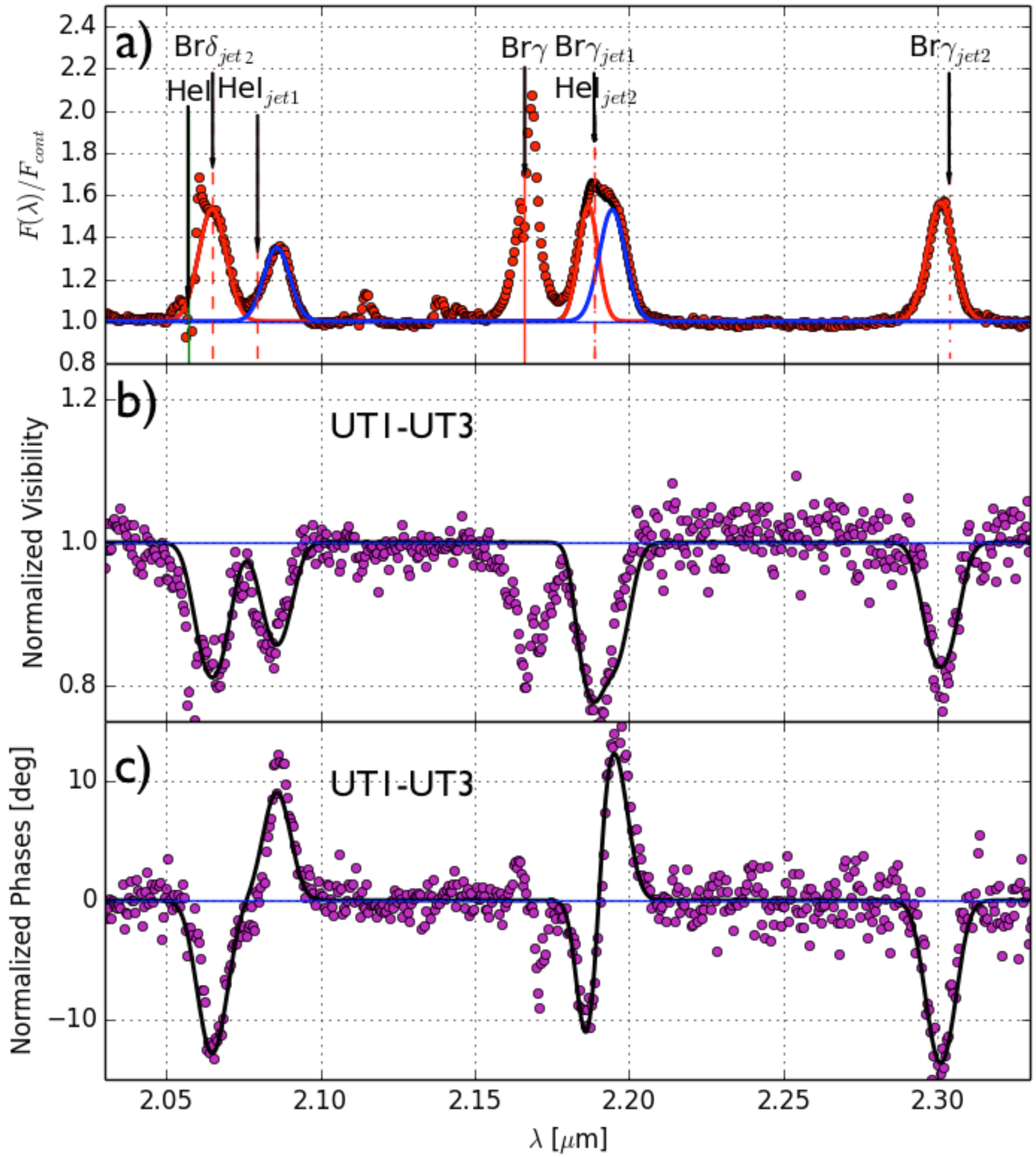


Blundell et al. 2004, ApJ, 616, L159

Distance 5.5 kpc
Orbital period 13.1 days
Precession period 162.5 days

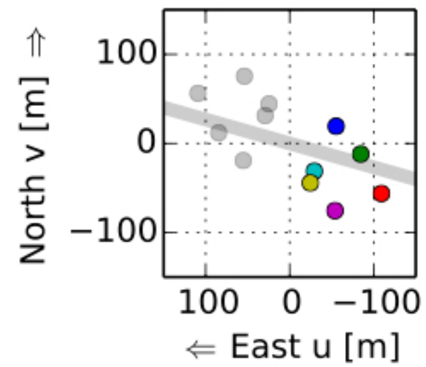
GRAVITY on SS 433

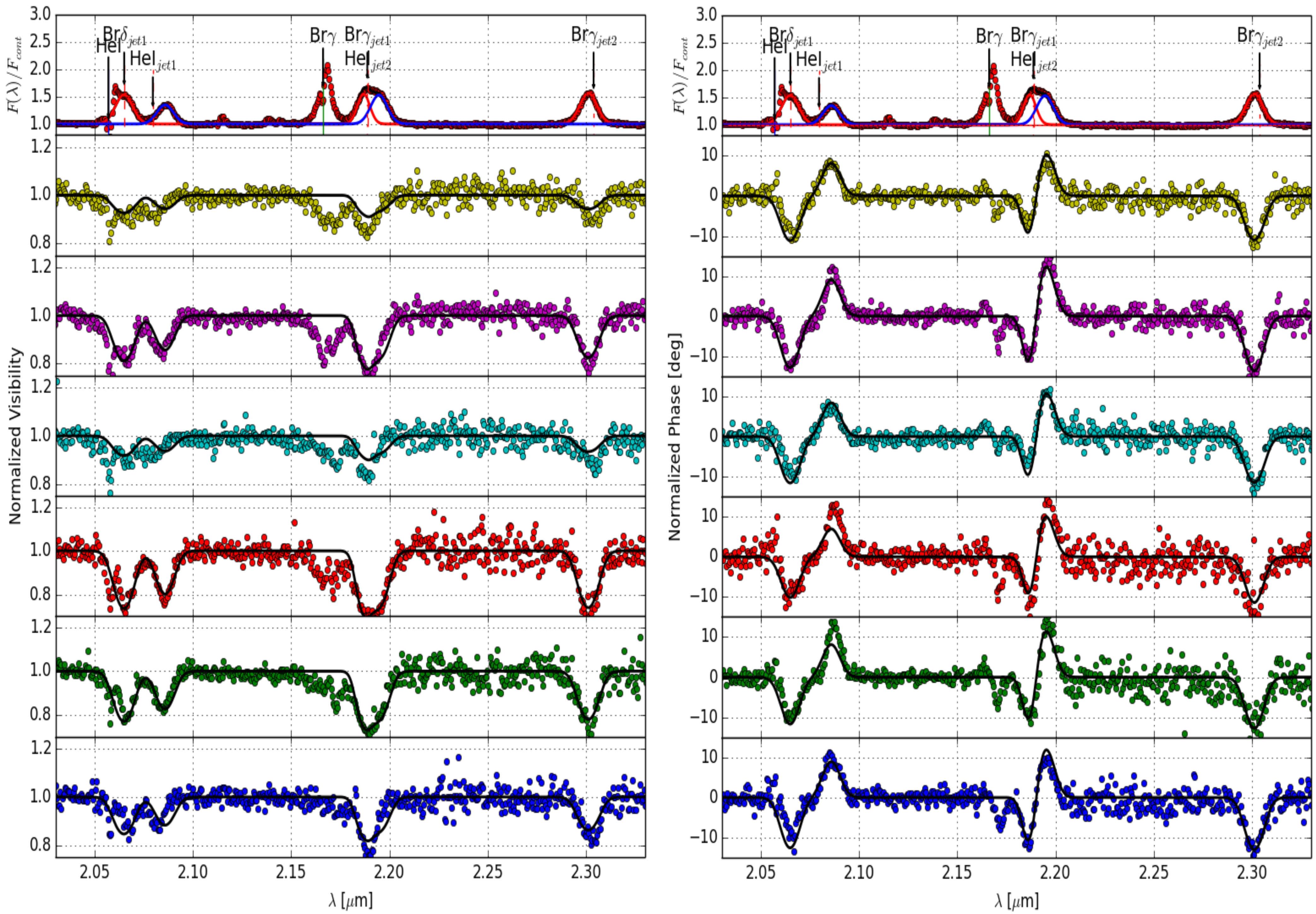
- Observations with 4 UTs in July 2016
- Complex spectrum due to Doppler line shifts



Petrucci et al. 2017, A&A, 602, L11

SS 433 Visibilities and diff. Phases

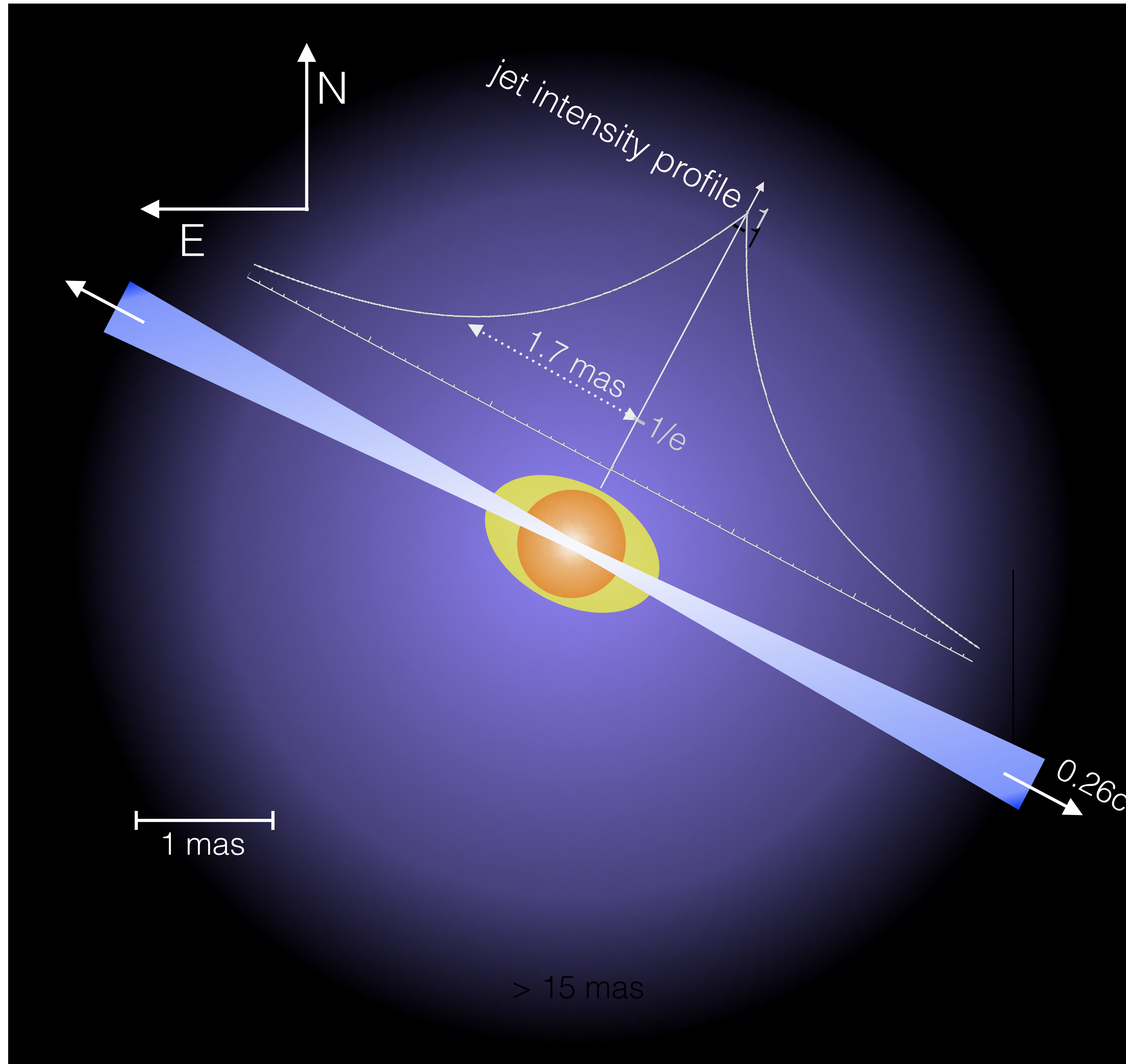




Petrucci et al. 2017, A&A, 602, L11

SS 433's central engine

- Central continuum source 0.8 mas
- Unresolved transverse width of jets
- New observations are foreseen over the orbital and precession cycle

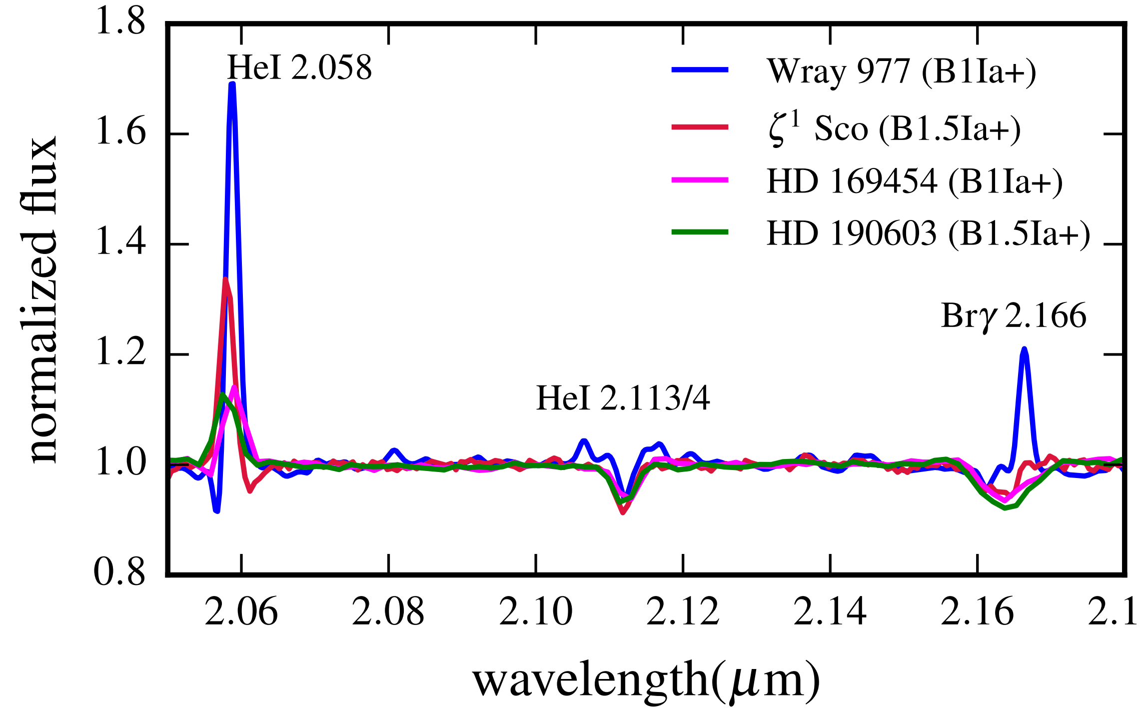


Petrucci et al. 2017, A&A, 602, L11

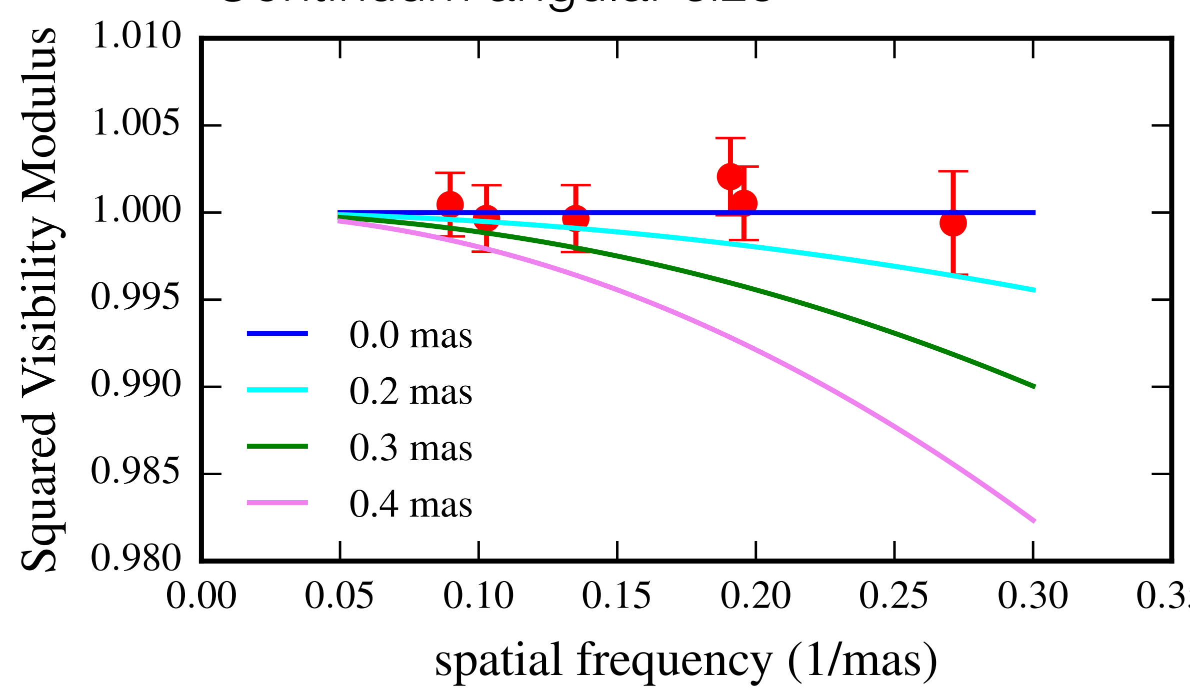
The HMXB BP Crucis

- Blue hypergiant donor (wind) ~40 Msun
- Accreting neutron star (pulsar) >1.8 Msun
- Orbital period 41.5 d
- Distance ~ 3 kpc
- mK~5.7
- Observed with 4 UTs in May 2016, R=4000

Spectrum



Continuum angular size



Waisberg et al. 2017, ApJ, 844, 72

BP Cru spectro-astrometry

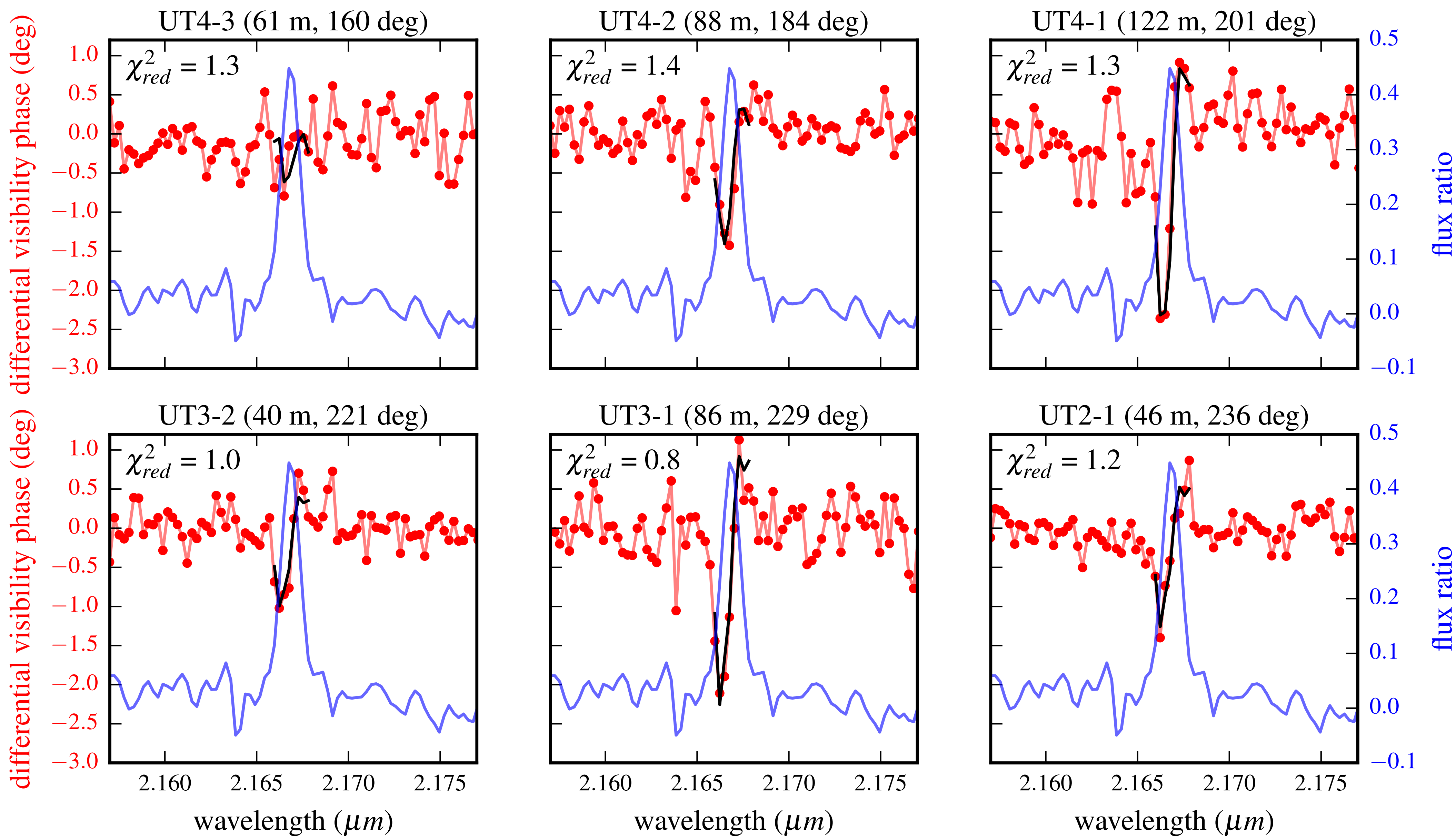


Figure 6. Differential visibility phases at Brγ line (red) and normalized photospheric-corrected flux ratio (blue). For each baseline, the projected baseline length and the position angle are also shown. In black, we show model-independent fits to the visibility phases (see text for details).

Waisberg et al. 2017, ApJ, 844, 72

BP Cru spectro-astrometry

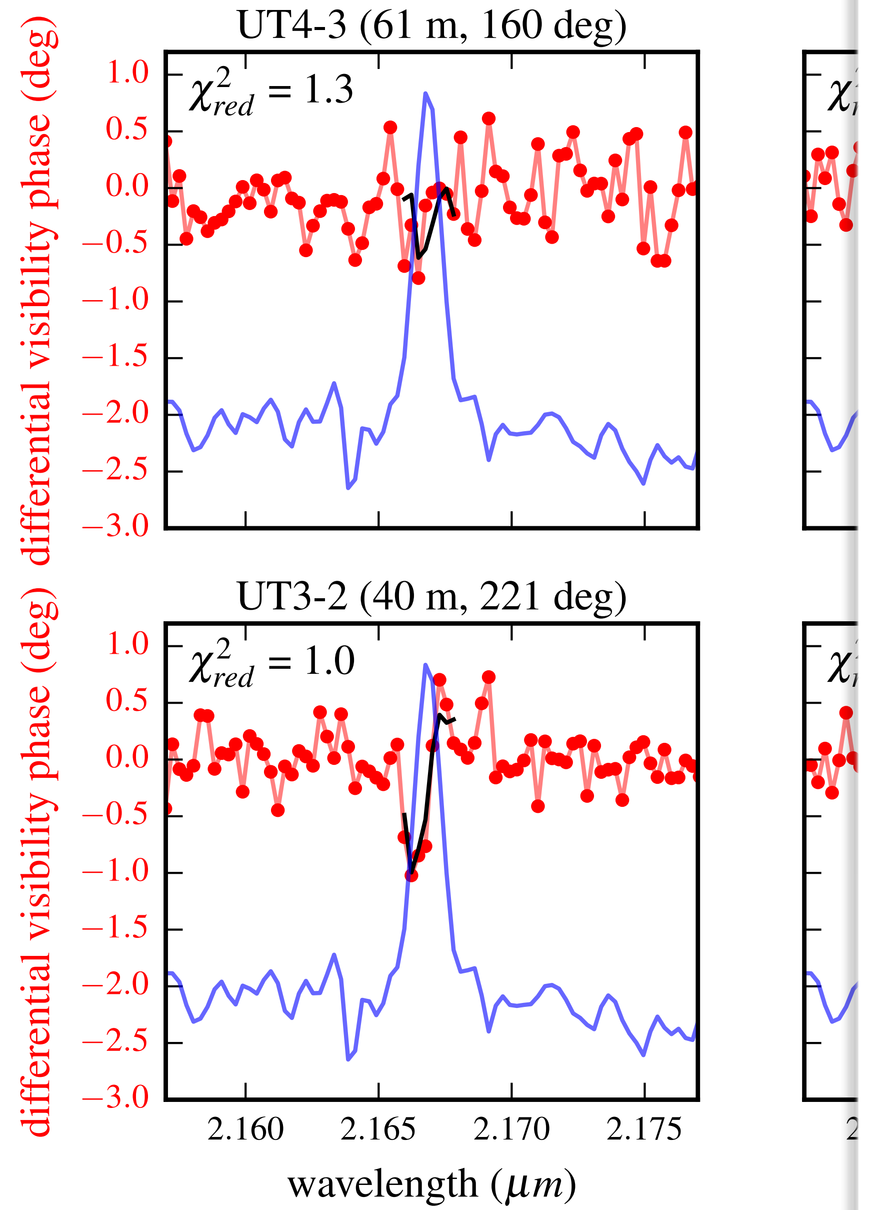
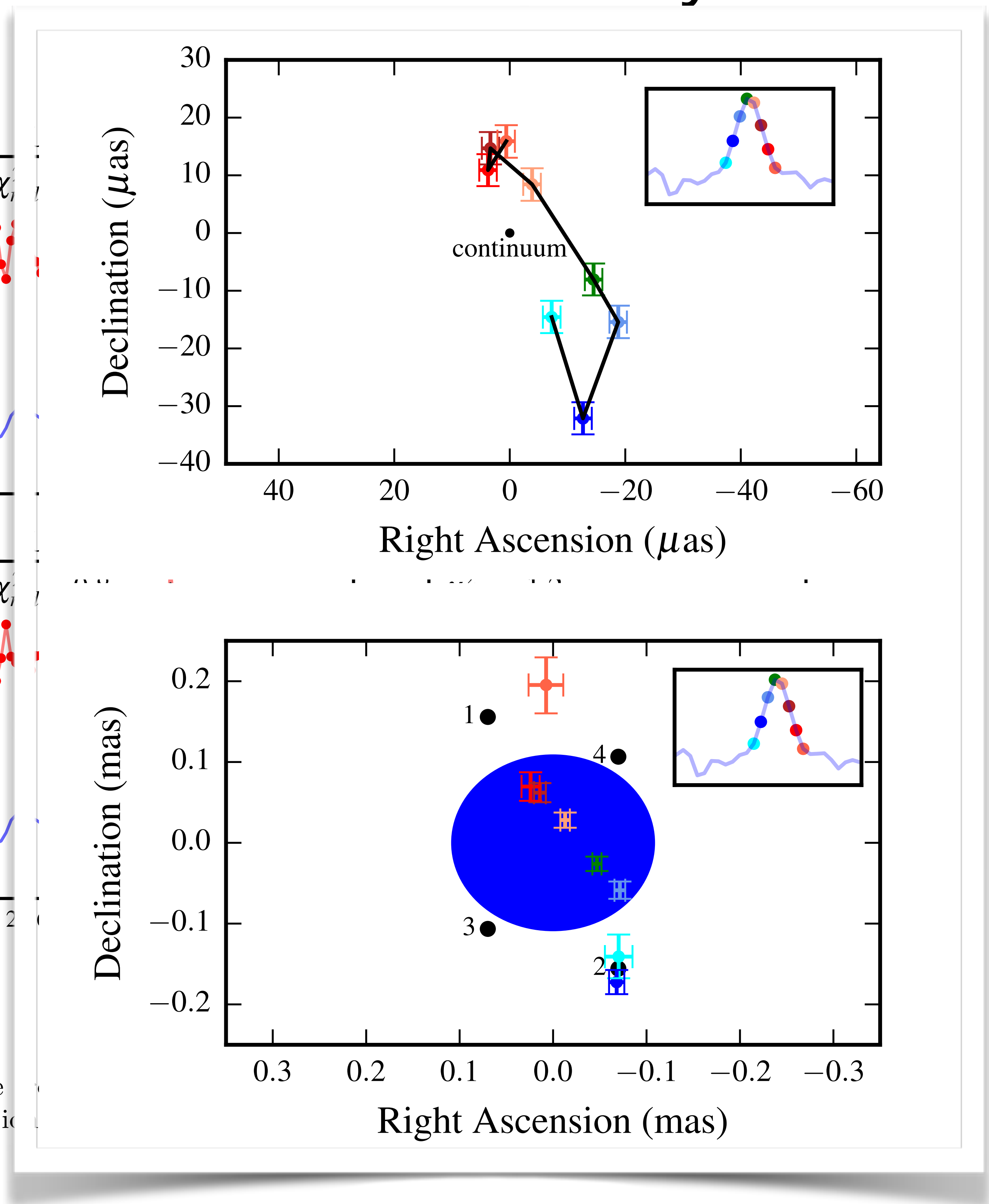
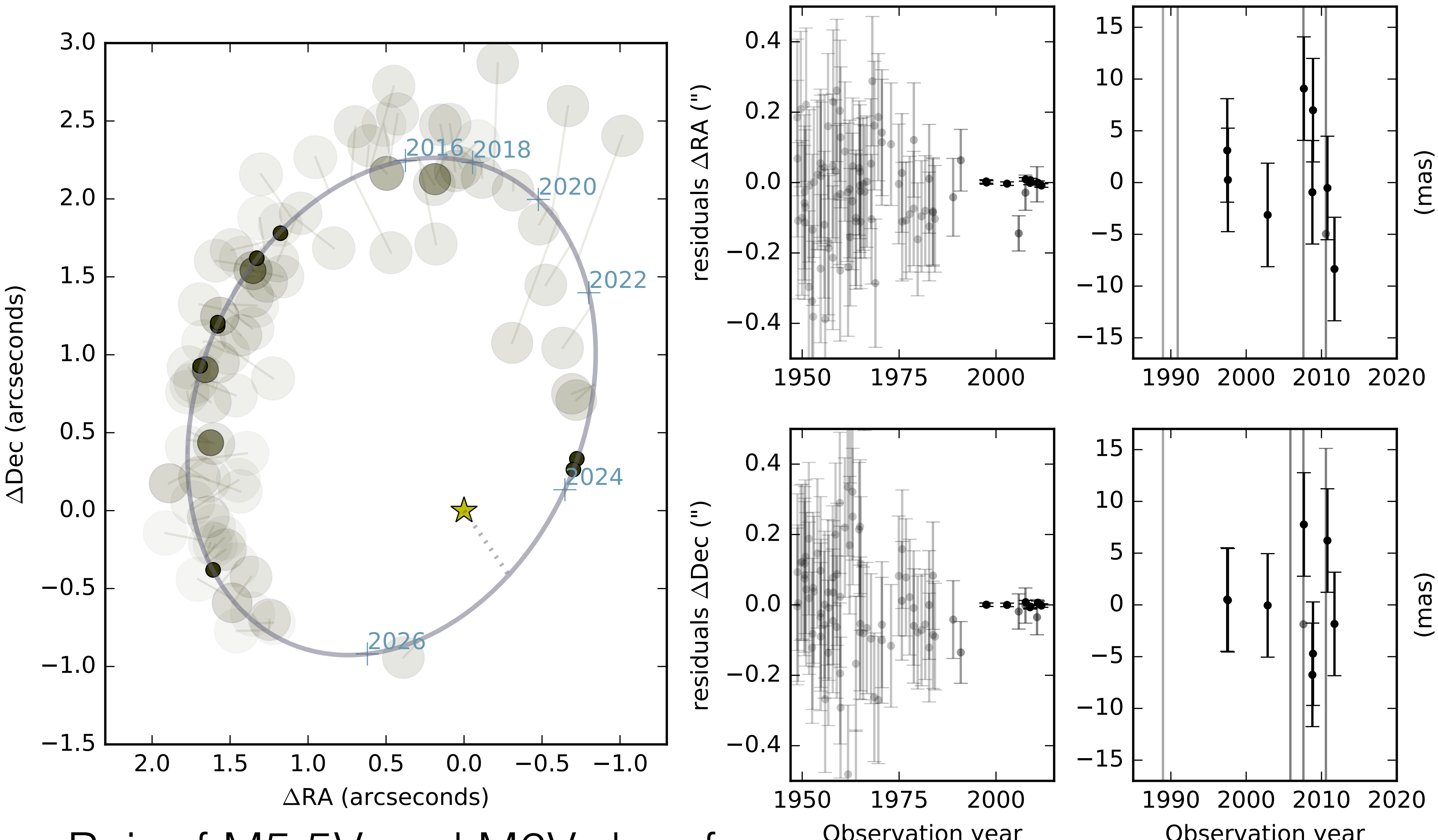


Figure 6. Differential visibility phases at Brγ line
baseline, the projected baseline length and the positi
visibility phases (see text for details).



Waisberg et al. 2017, ApJ, 844, 72

Red dwarf binary GJ 65 AB



- Pair of M5.5V and M6V dwarfs
- Orbital period 26 years
- Distance 2.7 pc

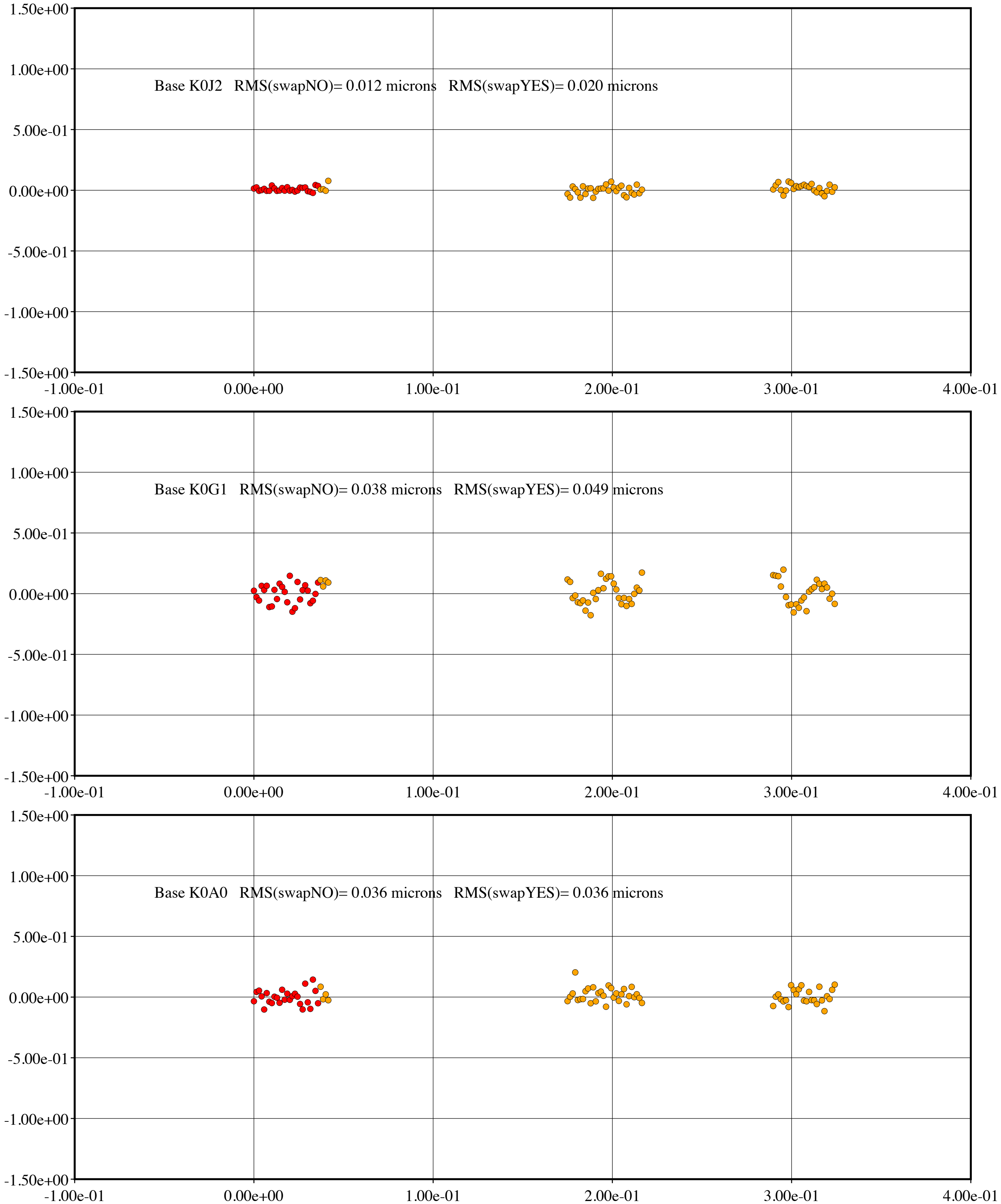
Kervella et al. 2016, A&A, 593, A127

Beam swapping of GJ 65 AB

(1/2) Residual dOPD from phase after FC+TEL GD fit

dOPD (mic) from WRAPPED phase vs. time (h), median over lbd.

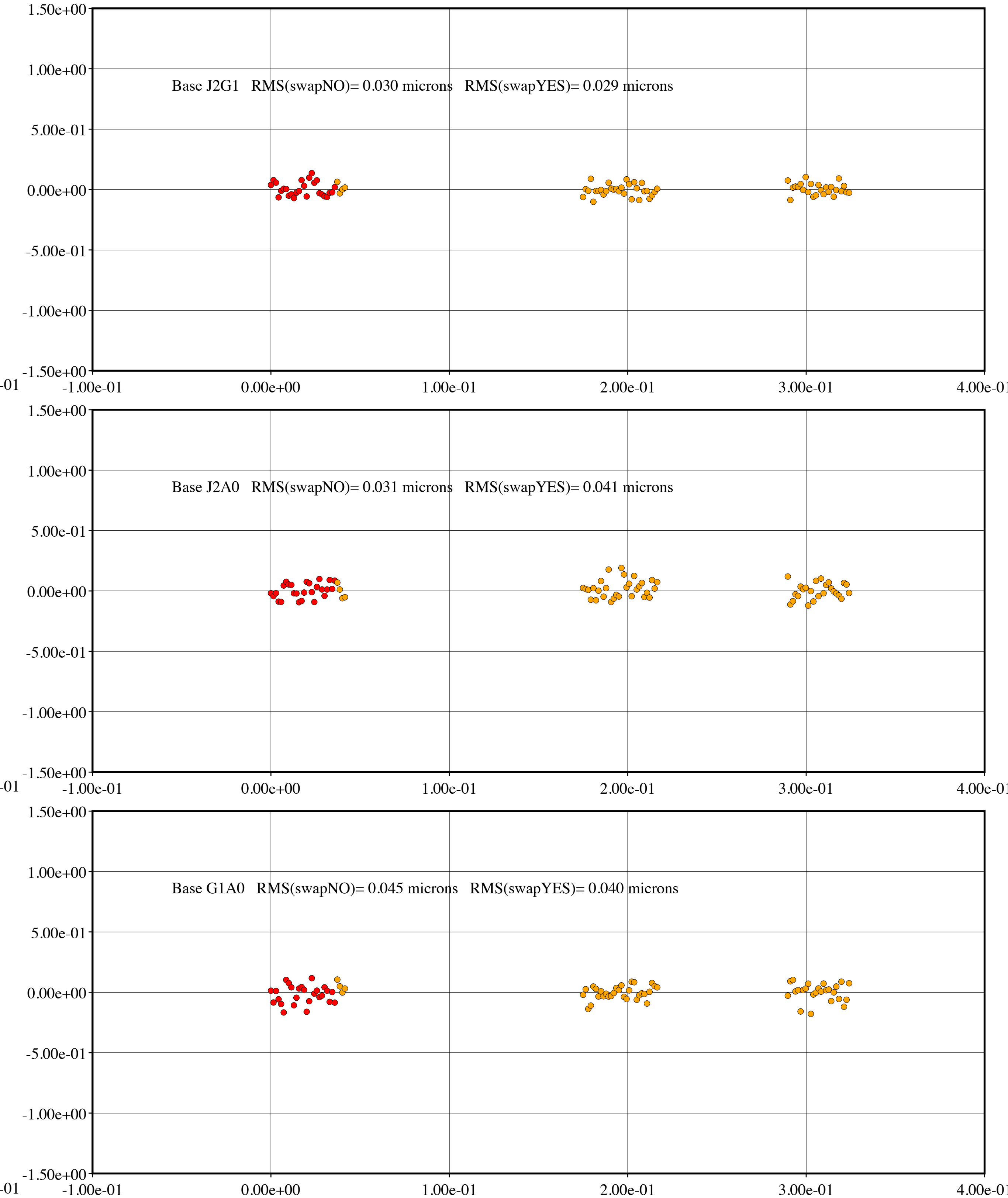
Swap with disp. corr.: NO=Red, YES=Orange x (-1).



(2/2) Residual dOPD from phase after FC+TEL GD fit

dOPD (mic) from WRAPPED phase vs. time (h), median over lbd.

Swap with disp. corr.: NO=Red, YES=Orange x (-1).



Differential Astrometry

- Fit uncertainty on separation = 15 µas

1) Separation of GJ65AB from orbit (Kervella et al. 2016):

R = 2270.291 +/- 10.670 mas, theta = 4.03006 +/- 0.20000 deg

2) GD only solution

X[mas]	199.915788087	0.0607774902377
Y[mas]	2261.0195391	0.0942522207819
ZPT_A0[um]	0	0
ZPT_G1[um]	133.407410931	0.0344993361563
ZPT_J2[um]	-48.4683209371	0.0348231545561
ZPT_K0[um]	-46.0374447677	0.0345719101944
Reduced Chi2	1.79977488149e-13	-

R = 2269.840 +/- 0.099 mas, theta = 5.05286 +/- 0.00154 deg
dR = -0.450 mas = -0.0 sigmas, dtheta = 1.02280 deg = 5.1 sigmas

3) Second fit of residual phasor of GD fit with FC MET ONLY

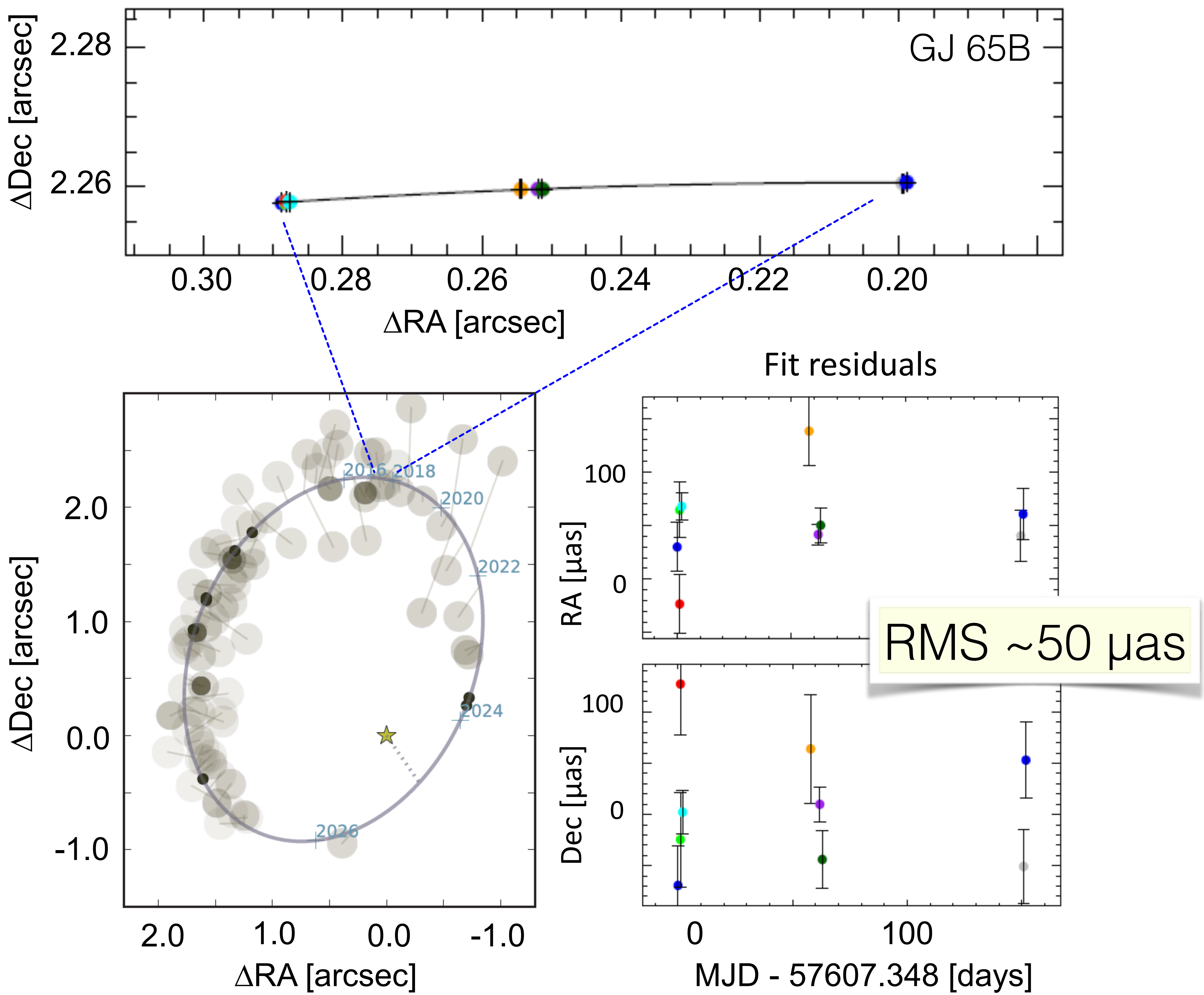
X[mas]	0.00250325172341	0.00952135478288
Y[mas]	-0.015991971251	0.0147654802729
ZPT_A0[um]	0	0
ZPT_G1[um]	0.00530530497052	0.00540463941557
ZPT_J2[um]	0.00608495609402	0.00545536855652
ZPT_K0[um]	0.00889438343264	0.00541600880845
Reduced Chi2	4.41702805725e-15	-

R = 2269.825 +/- 0.016 mas, theta = 5.05296 +/- 0.00024 deg
dR = -0.466 mas = -0.0 sigmas, dtheta = 1.02290 deg = 5.1 sigmas

4) Second fit of residual phasor of GD fit with FC+TEL MET

X[mas]	-0.00602873937791	0.00900571530611
Y[mas]	-0.0205746112088	0.0139658393924
ZPT_A0[um]	0	0
ZPT_G1[um]	0.0065121615682	0.00511194520305
ZPT_J2[um]	0.00564429269308	0.00515992705138
ZPT_K0[um]	0.00905424130637	0.00512269887391
Reduced Chi2	3.95156462743e-15	-

R = 2269.819 +/- 0.015 mas, theta = 5.05276 +/- 0.00023 deg
dR = -0.471 mas = -0.0 sigmas, dtheta = 1.02270 deg = 5.1 sigmas



GRAVITY Collaboration 2017, A&A, 602, A94

The α Centauri system

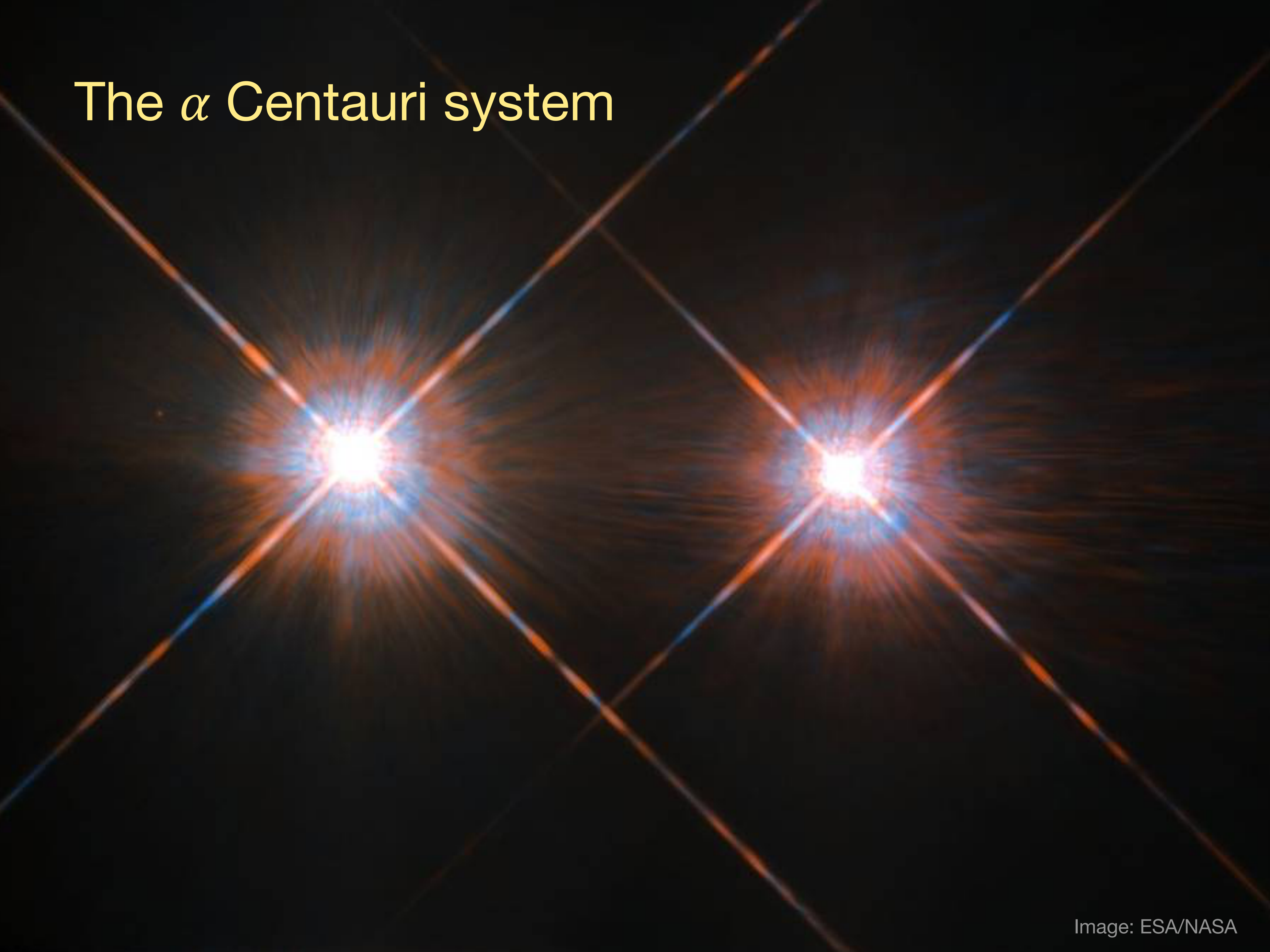
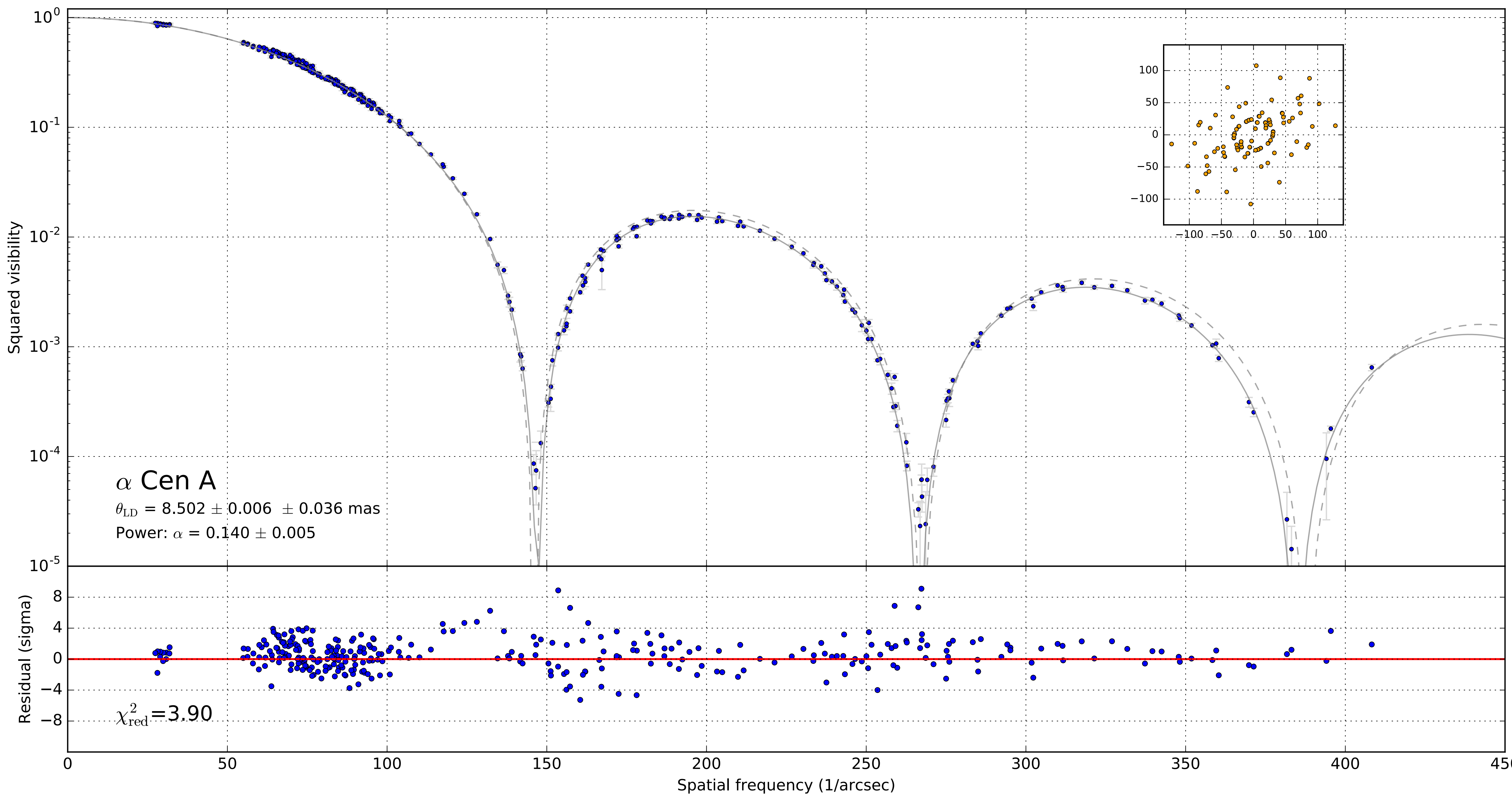


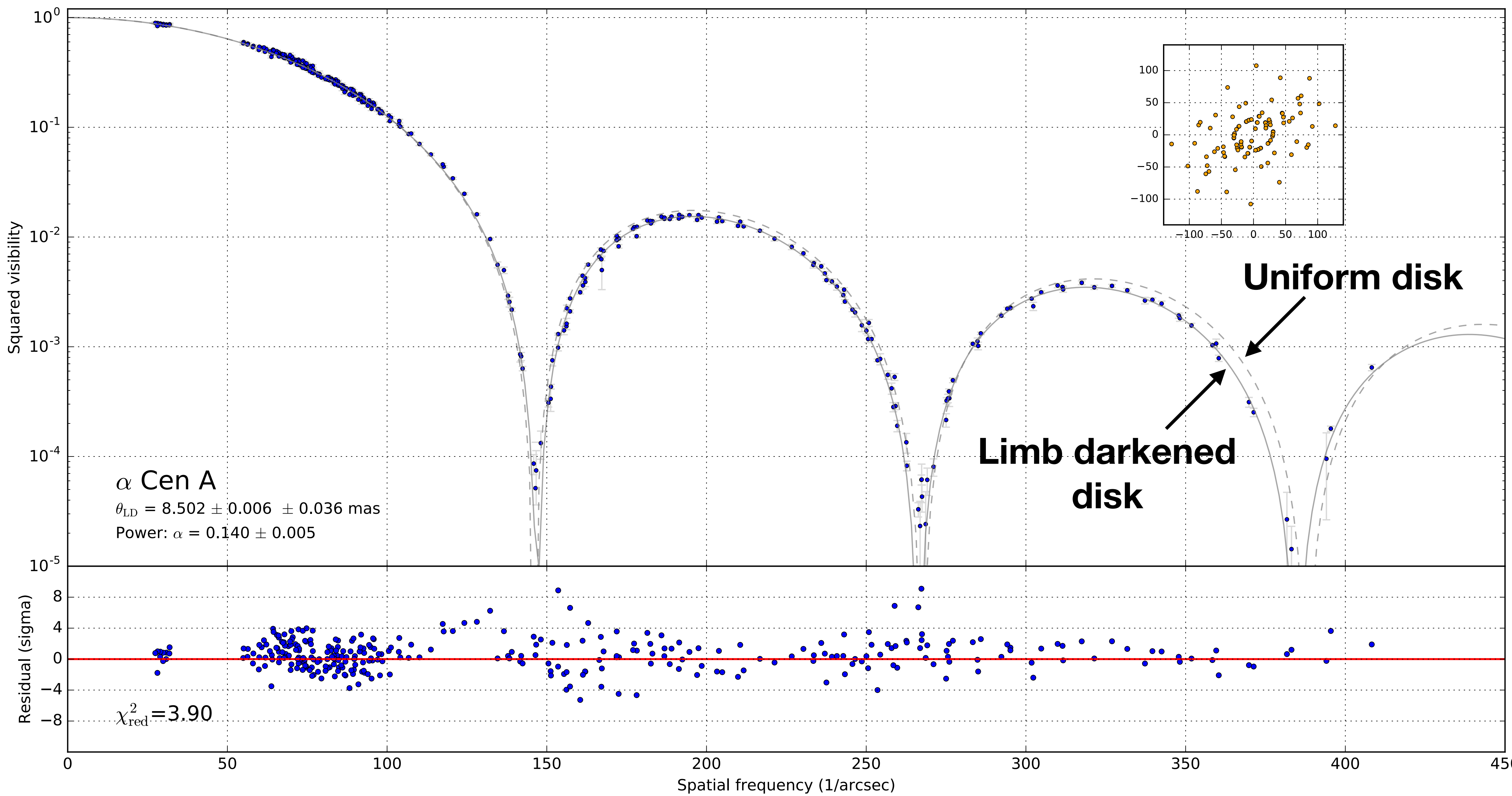
Image: ESA/NASA

VLTI/PIONIER observations

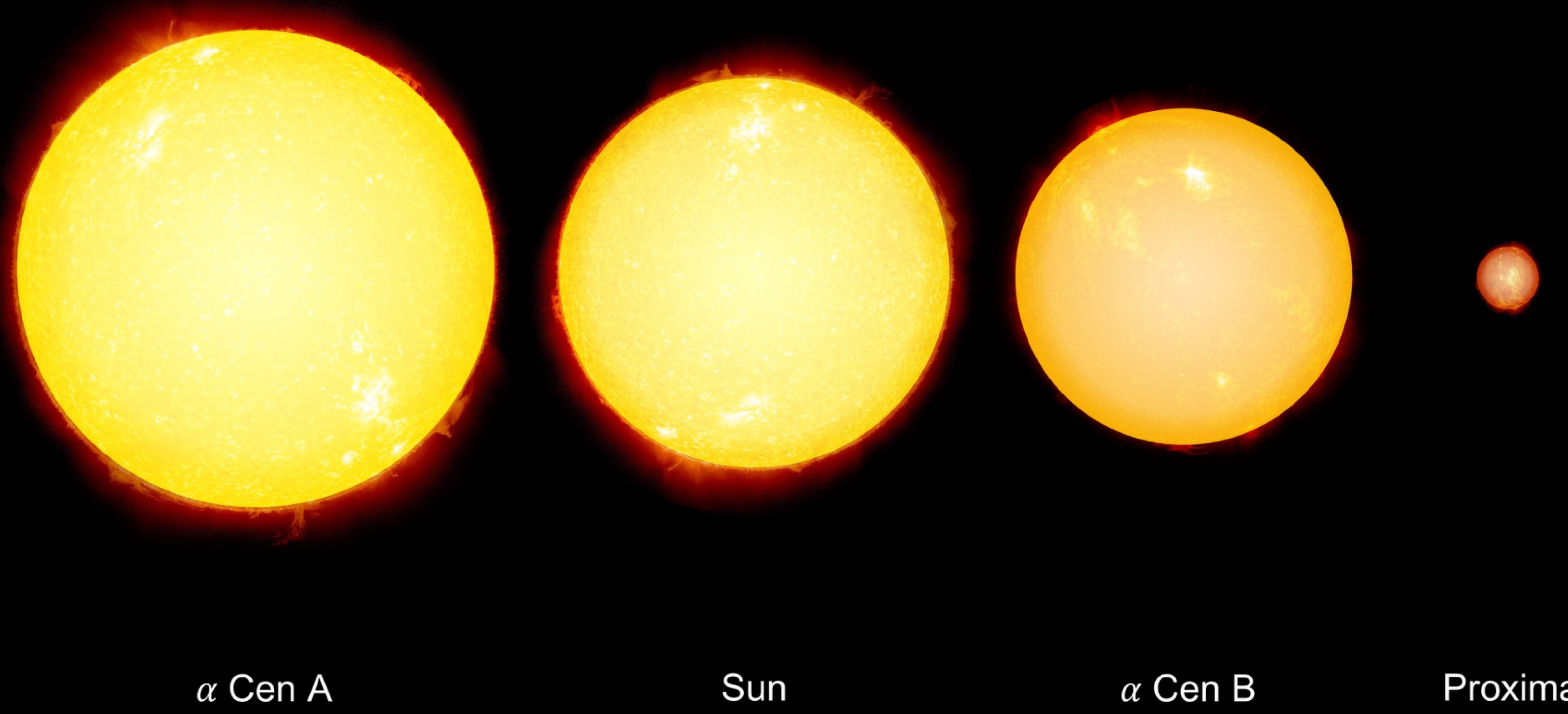


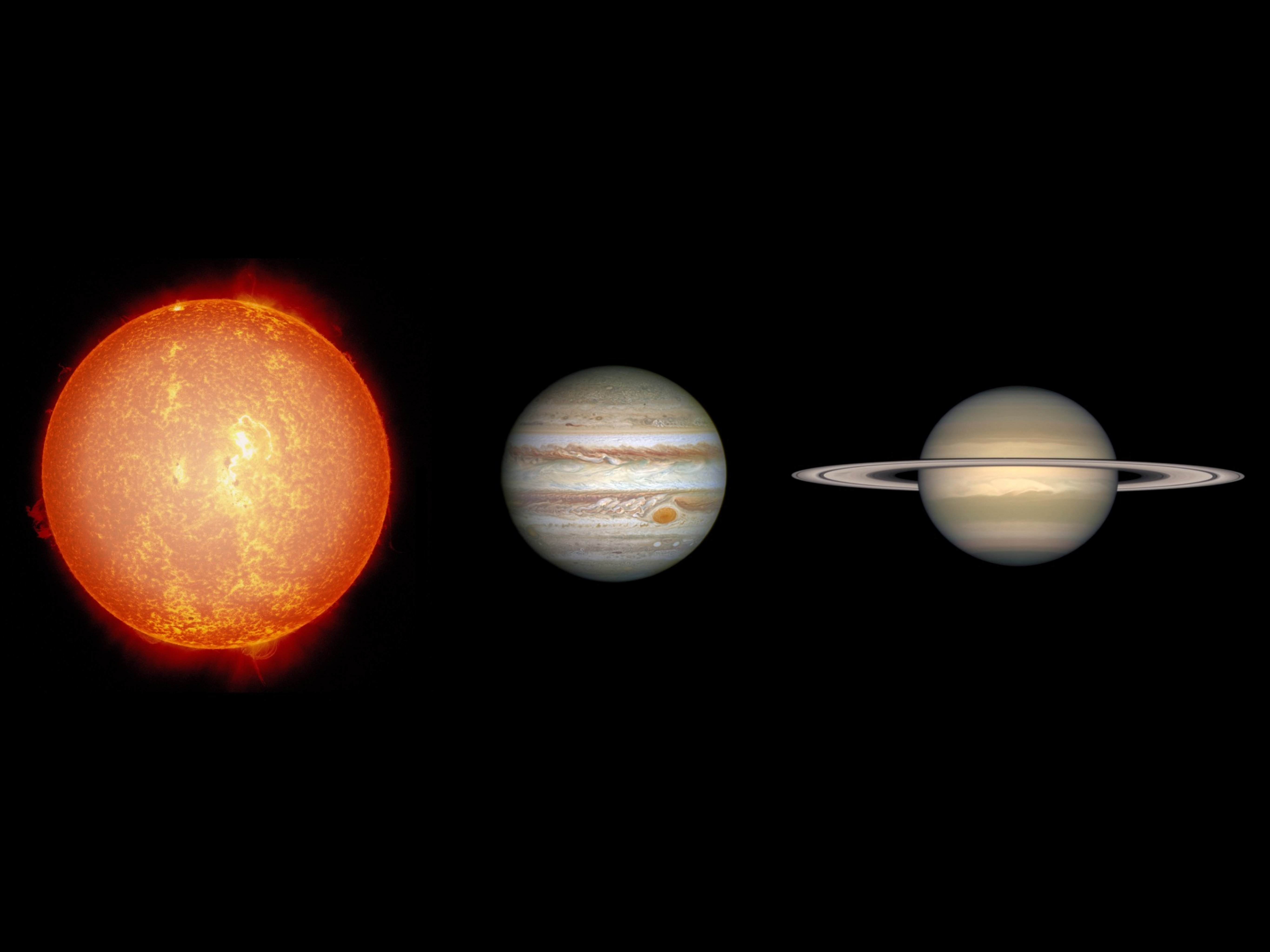
Kervella et al. 2017, A&A, 597, A137

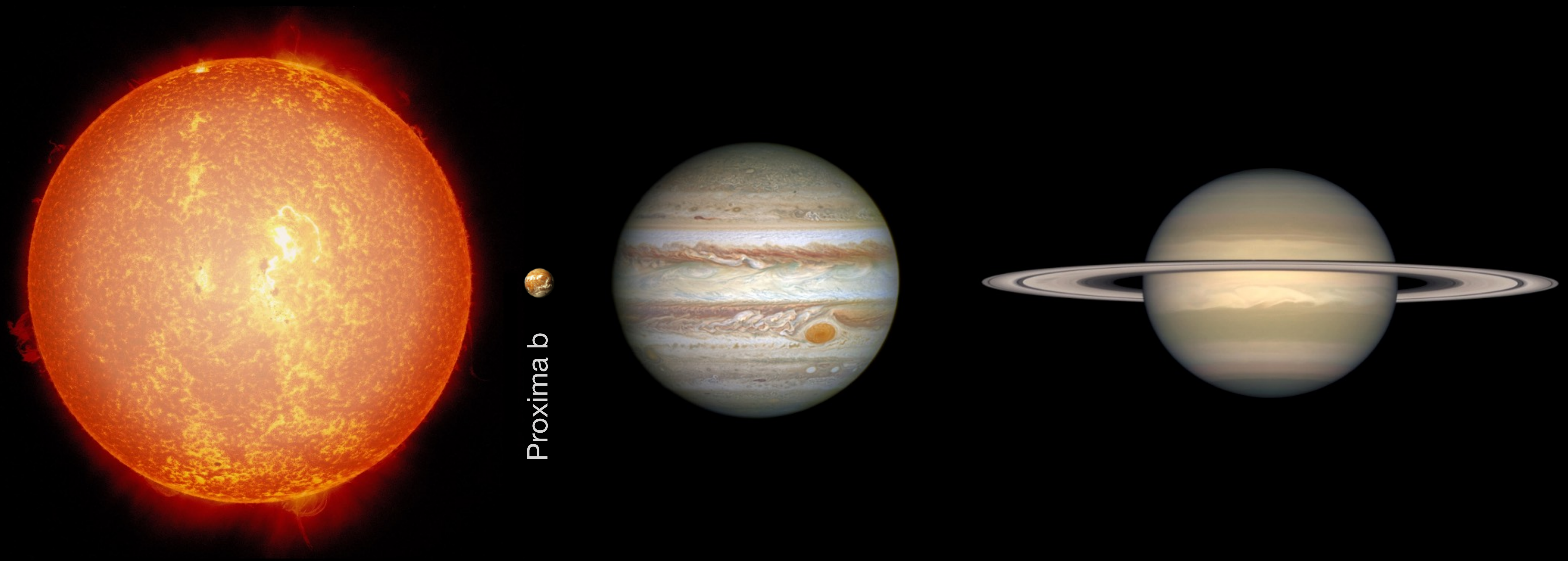
VLTI/PIONIER observations



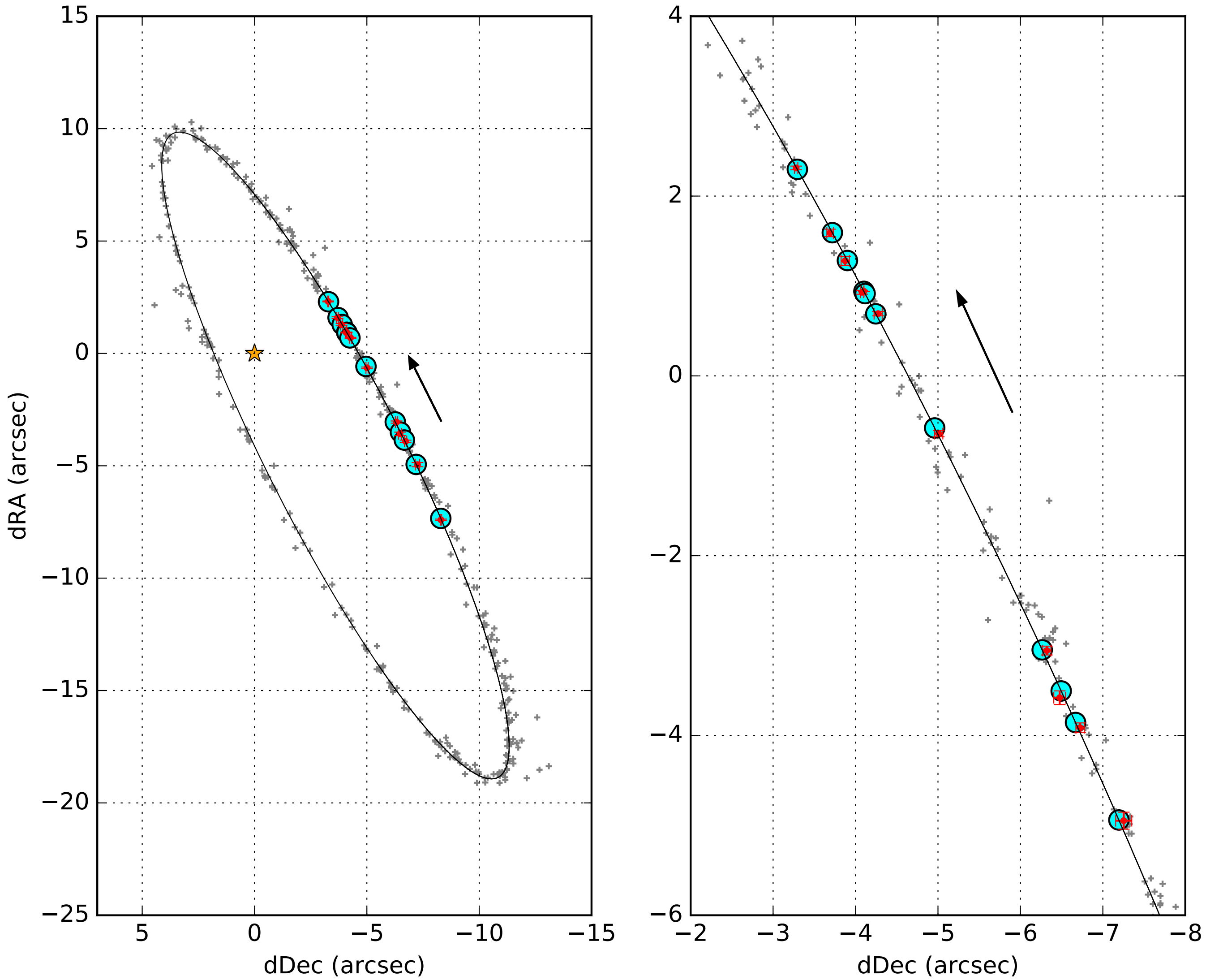
Kervella et al. 2017, A&A, 597, A137

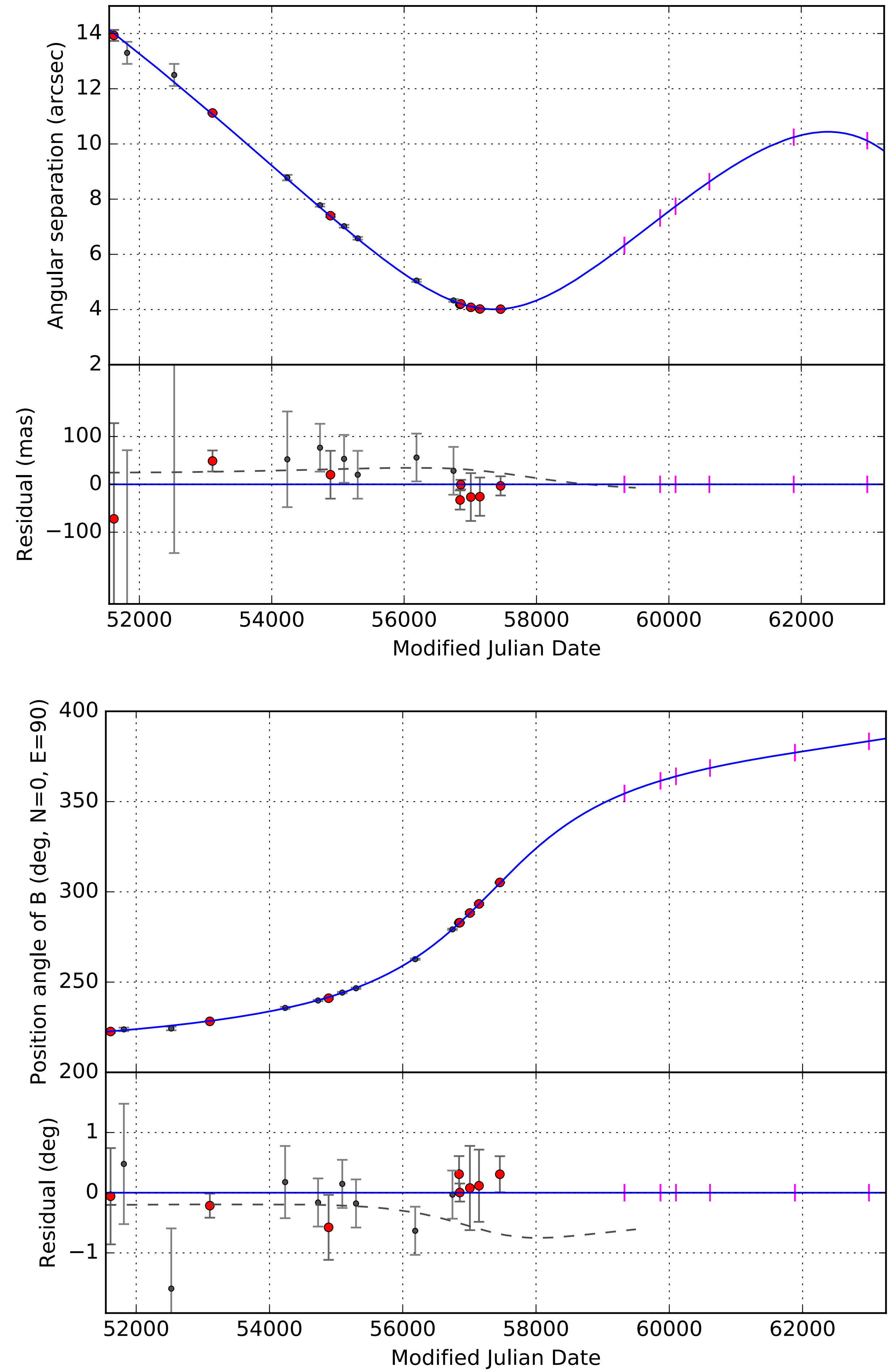

α Cen A
Sun
α Cen B
Proxima




Proxima b

A-B orbit



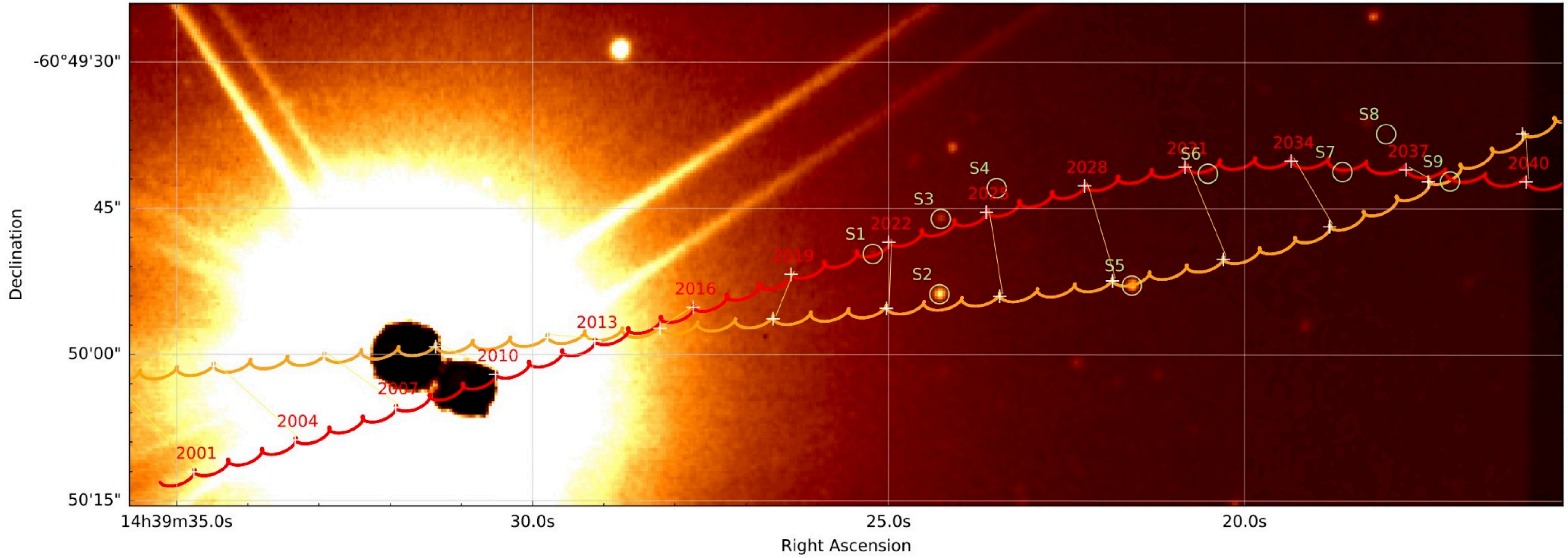


- Accurate orbital parameters, masses (0.4%) and barycentric parallax (0.09%)

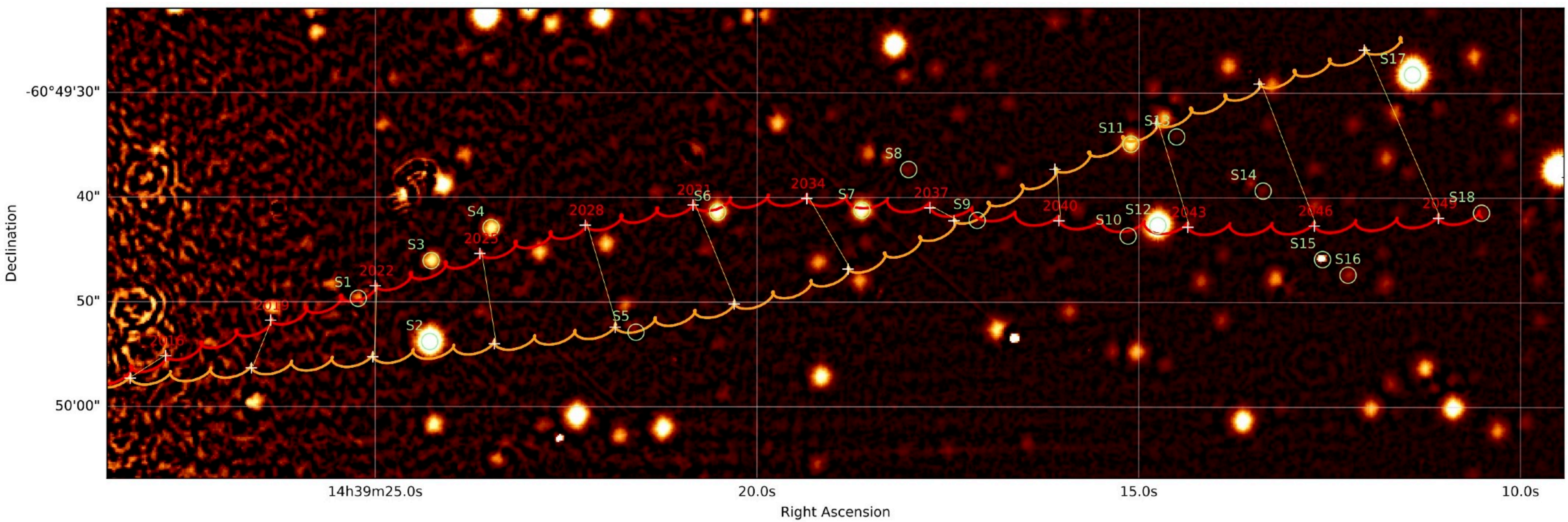
Kervella et al. A&A 594, A107 (2016)

Stellar conjunctions

- Now that we have the trajectories, let's see which stars come close
- Difficulty: star catalogues are incomplete around bright stars



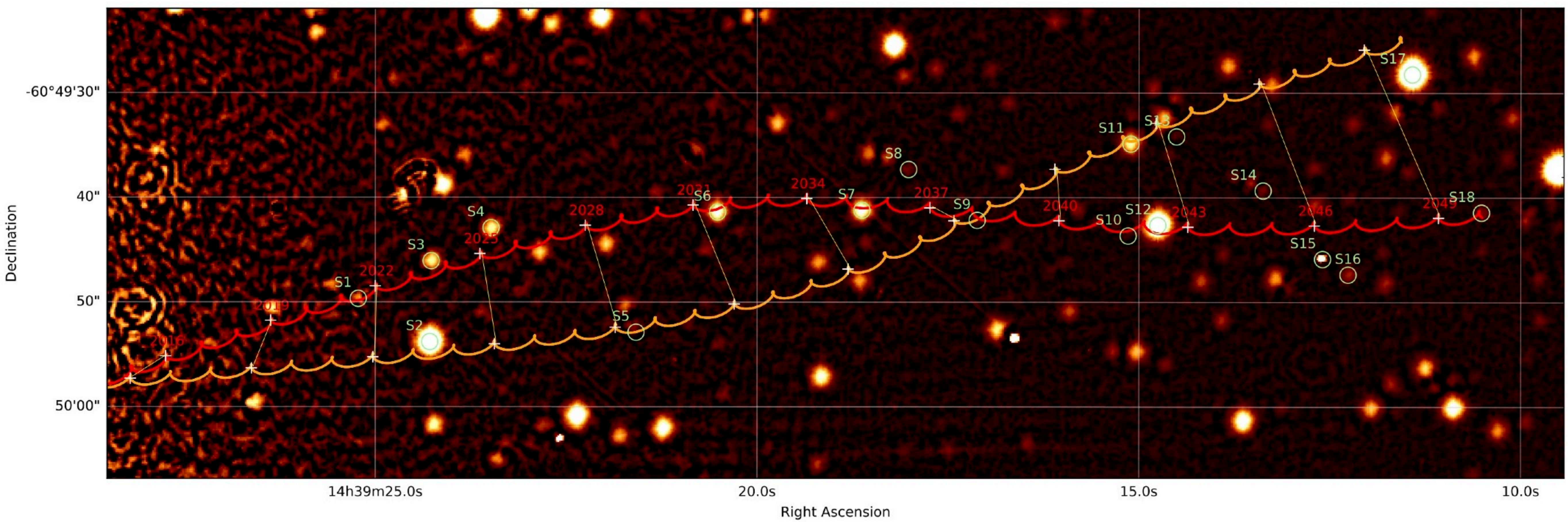
Opportunities in the coming years



★[a]	$\rho_{\min}['']$	Date[b]	#[c]	K07[d]	m_V	ΔV	m_I	ΔI	m_K	ΔK	RA	Dec	Epoch	$\mu_\alpha{}^e$	$\mu_\delta{}^d$	$\sigma_\mu{}^d$
B	0.205 ± 0.177	2021-05-03	S1	1266	$20.0_{0.5}$	18.7	$17.6_{0.2}$	17.2	$13.58_{0.17}$	14.2	14:39:25.224	−60:49:49.67	2009.152	−5	−12	12
A	1.643 ± 0.112	2023-04-27	S2	1184	$15.7_{0.2}$	15.7	$13.3_{0.2}$	13.9	$11.14_{0.03}$	12.6	14:39:24.283	−60:49:53.80	2016.236	+2	−2	5
B	1.354 ± 0.186	2023-12-12	S3	1181	$19.7_{0.3}$	18.4	$16.0_{0.2}$	15.6	$12.89_{0.11}$	13.5	14:39:24.264	−60:49:46.03	2009.152	+1	−4	11
B	2.433 ± 0.119	2024-10-26	S4	1113	$17.5_{0.2}$	16.2	$15.9_{0.2}$	15.5	–	–	14:39:23.485	−60:49:42.91	2016.236	+6	+8	5
A	0.015 ± 0.135	2028-05-06	S5	0951	$21.5_{0.9}$	21.5	$18.7_{0.3}$	19.3	$7.76_{0.02}$	9.3	14:39:21.586	−60:49:52.89	2016.236	−5	−5	5
B	0.269 ± 0.277	2031-05-25	S6	0856	$16.9_{0.2}$	15.6	$15.4_{0.2}$	14.9	–	–	14:39:20.518	−60:49:41.41	2009.152	−6	−1	11

Kervella et al. A&A 594, A107 (2016)

Opportunities in the coming years



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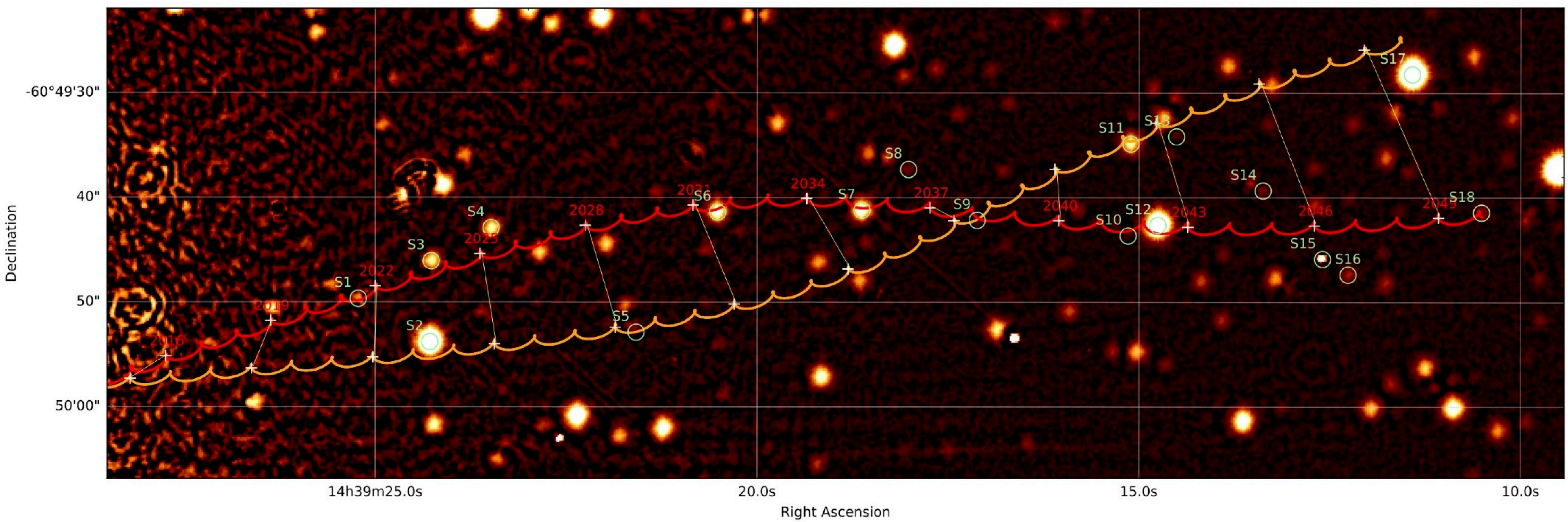
- With GRAVITY, we can measure the differential position of α Cen A and B and the background S stars to ~10 µas.

Kervella et al. A&A 594, A107 (2016)

Opportunities in the coming years



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- With GRAVITY, we can measure the differential position of α Cen A and B and the background S stars to ~10 µas.
- *Extraordinarily* accurate differential parallax and proper motion

Kervella et al. A&A 594, A107 (2016)

Conjunction with S5

Kervella et al. A&A 594, A107 (2016)

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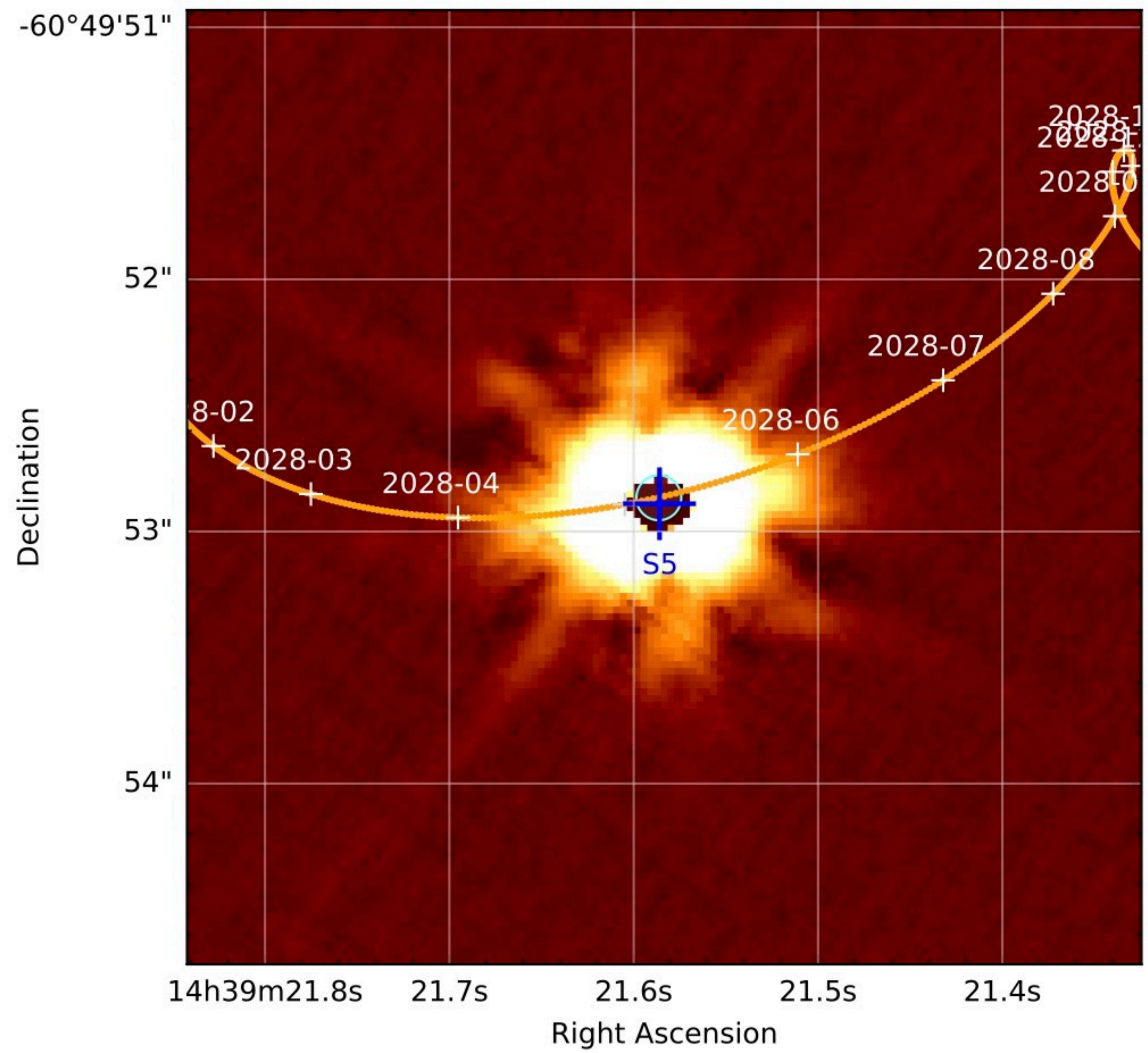
- In May 2028, α Cen A will come within 0.015 ± 0.135" of star S5



Kervella et al. A&A 594, A107 (2016)

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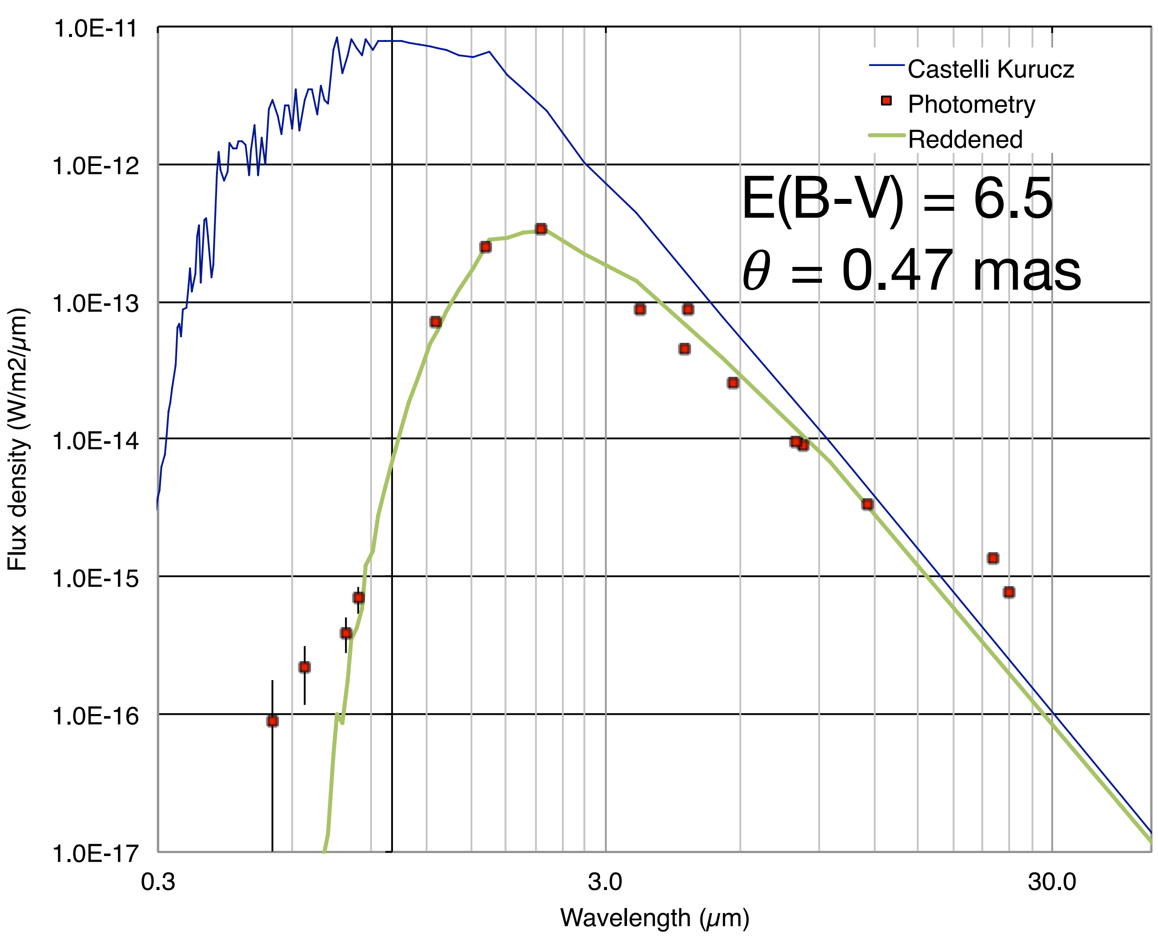
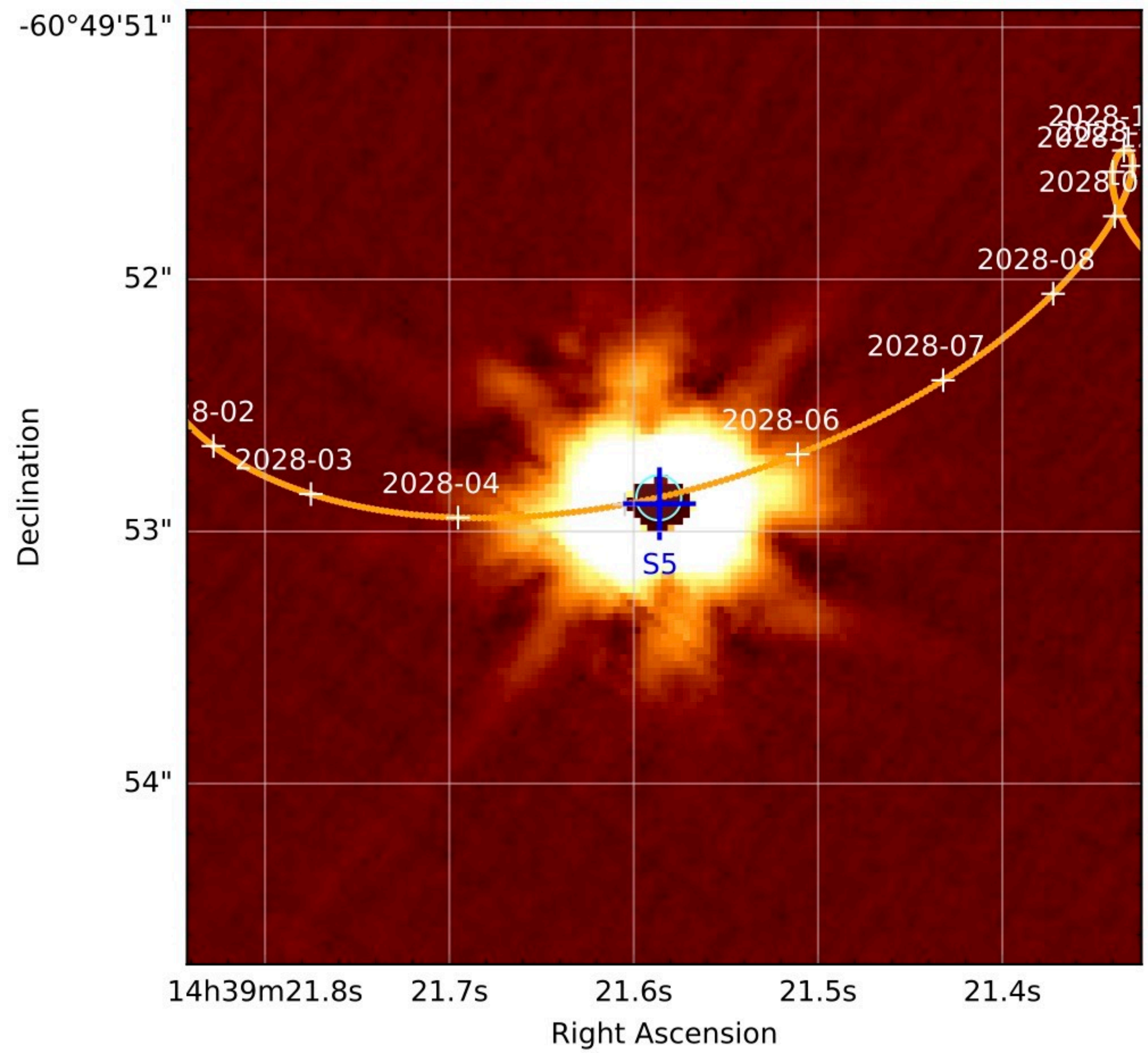
- S5 is faint in the visible, but bright in the infrared, K_s = 7.76





Kervella et al. A&A 594, A107 (2016)

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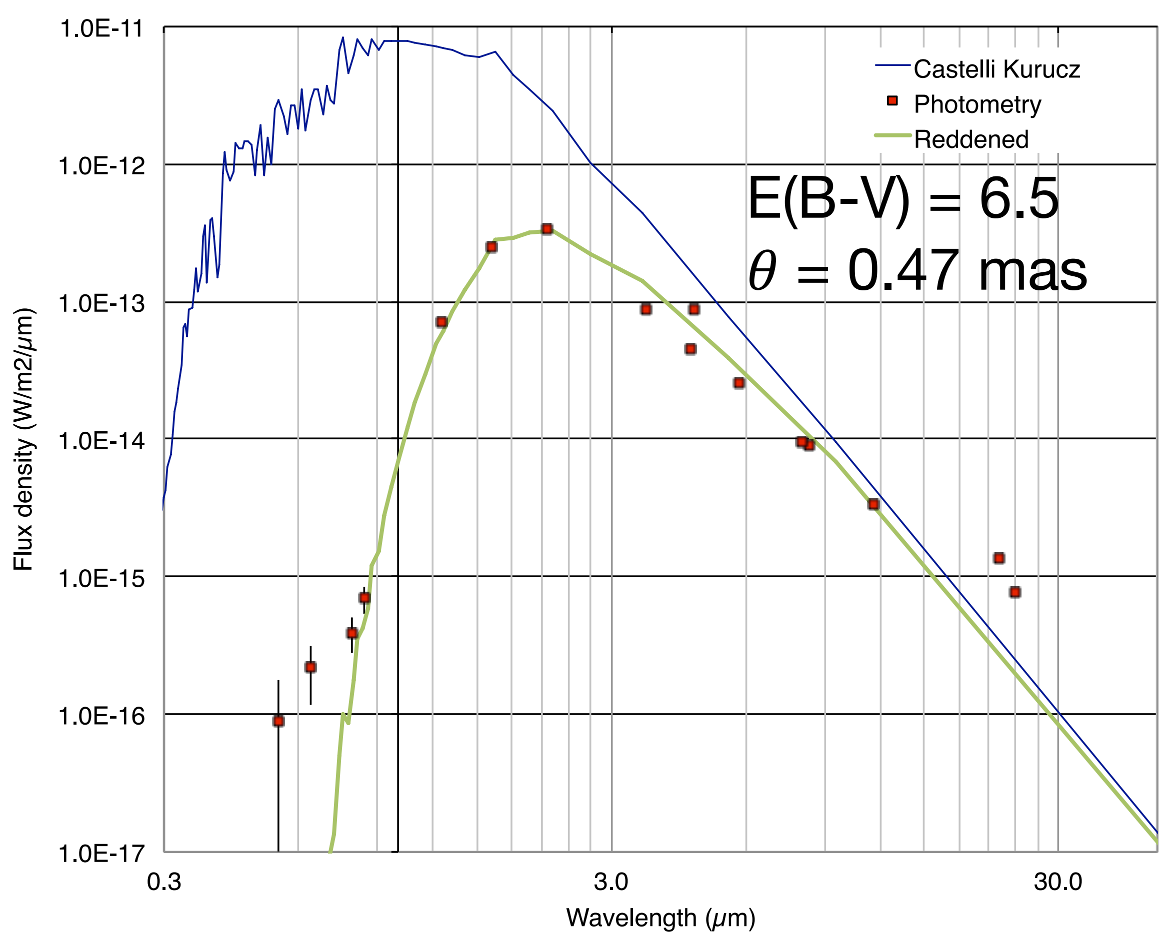

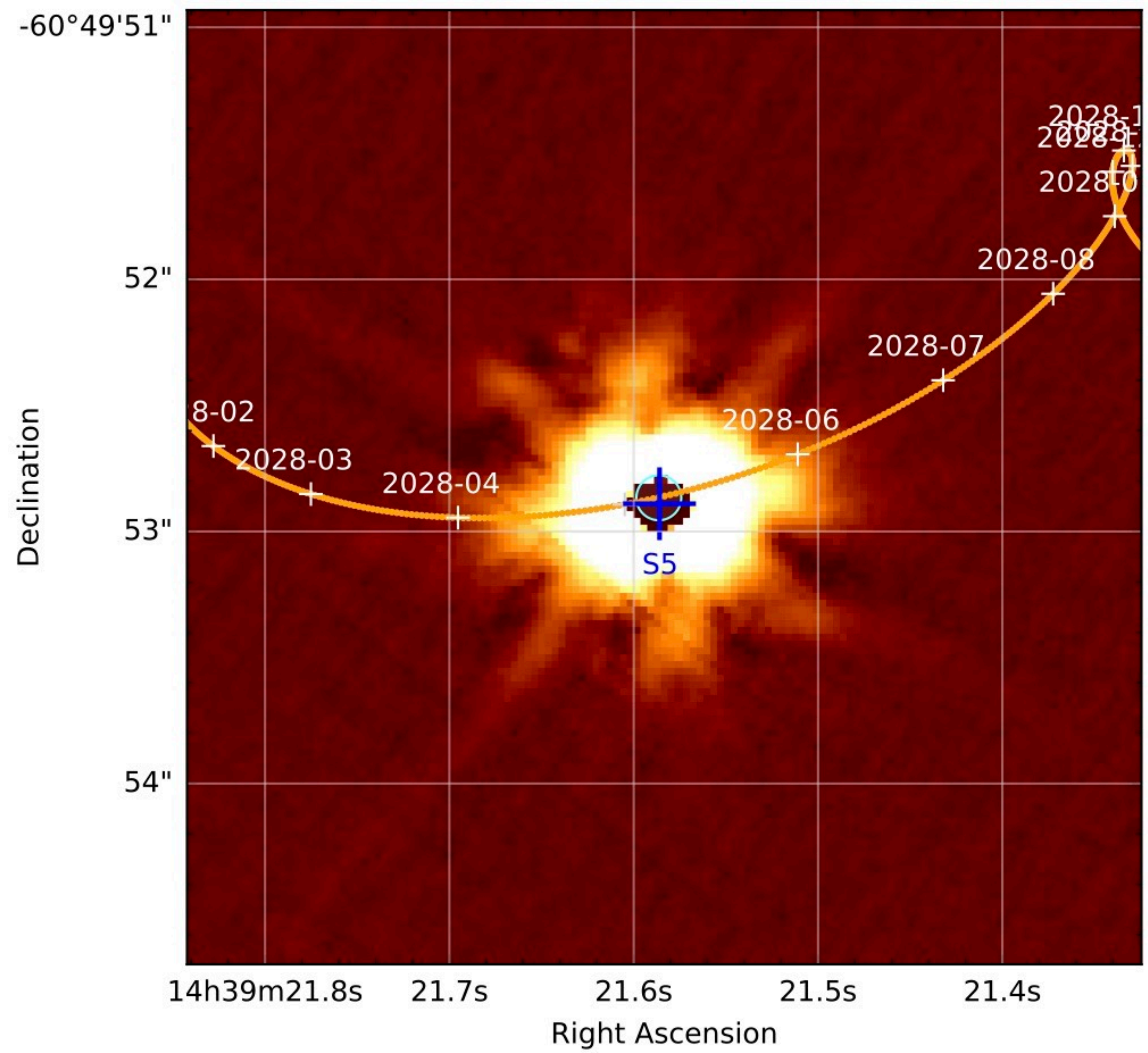

- S5 is likely a very distant red supergiant

Kervella et al. A&A 594, A107 (2016)

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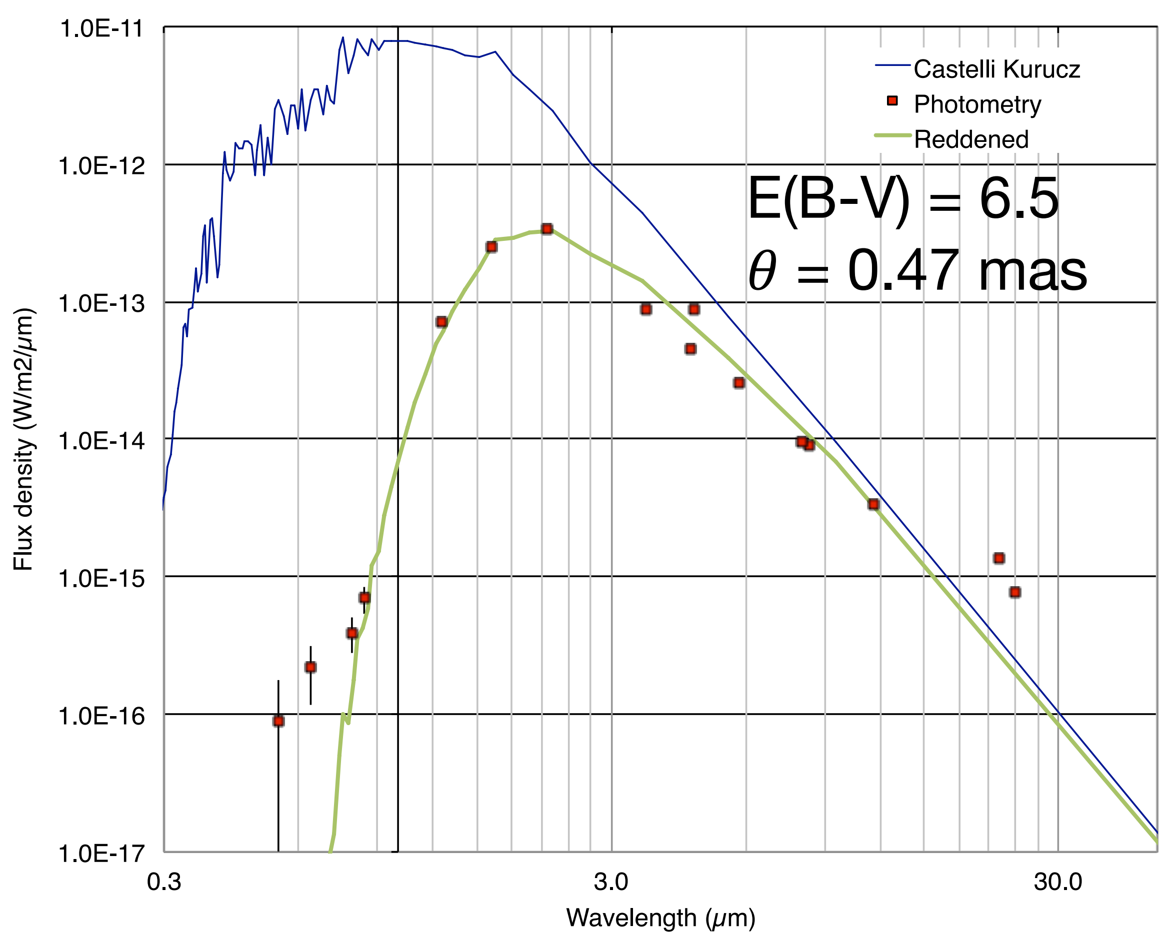
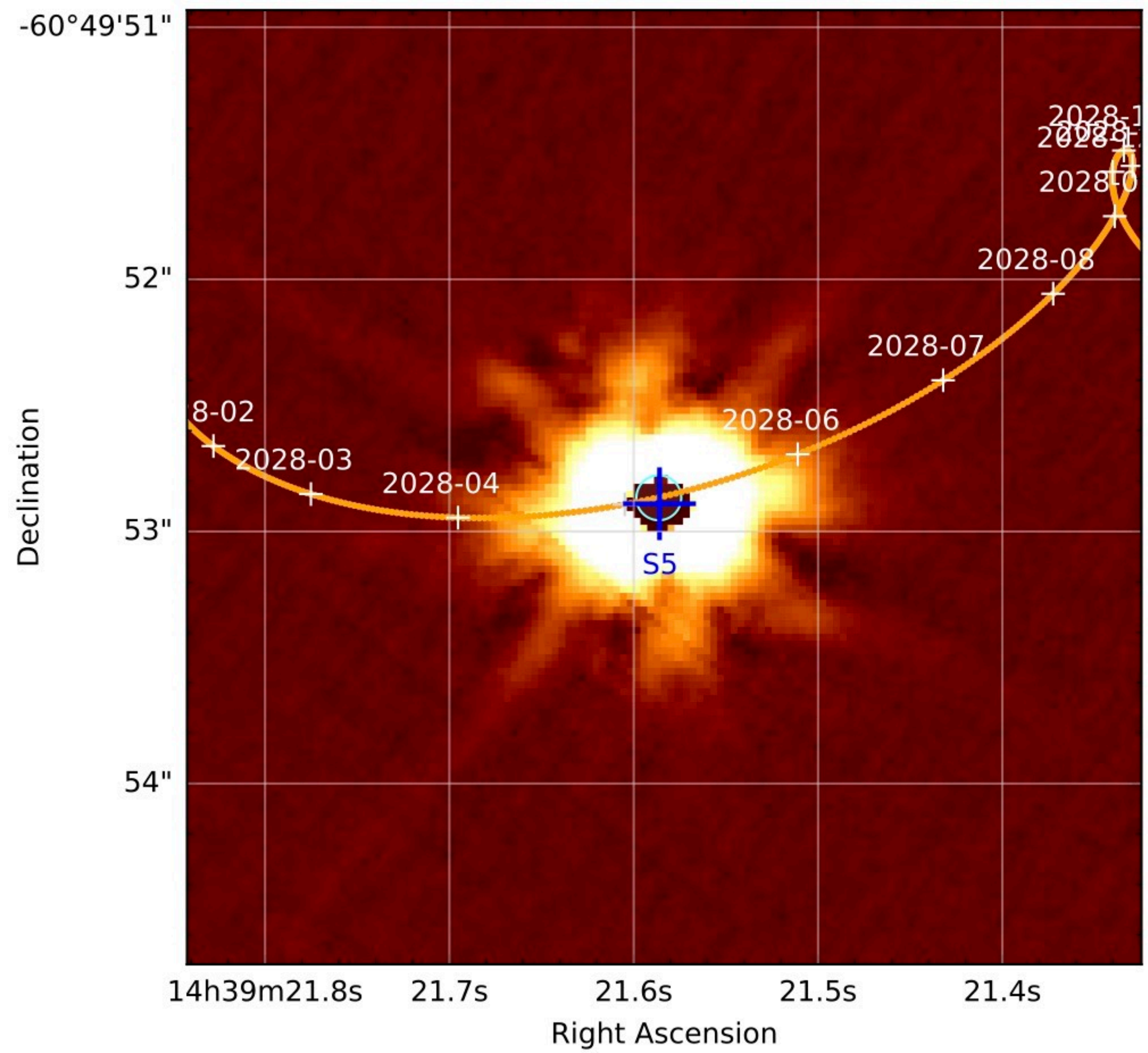
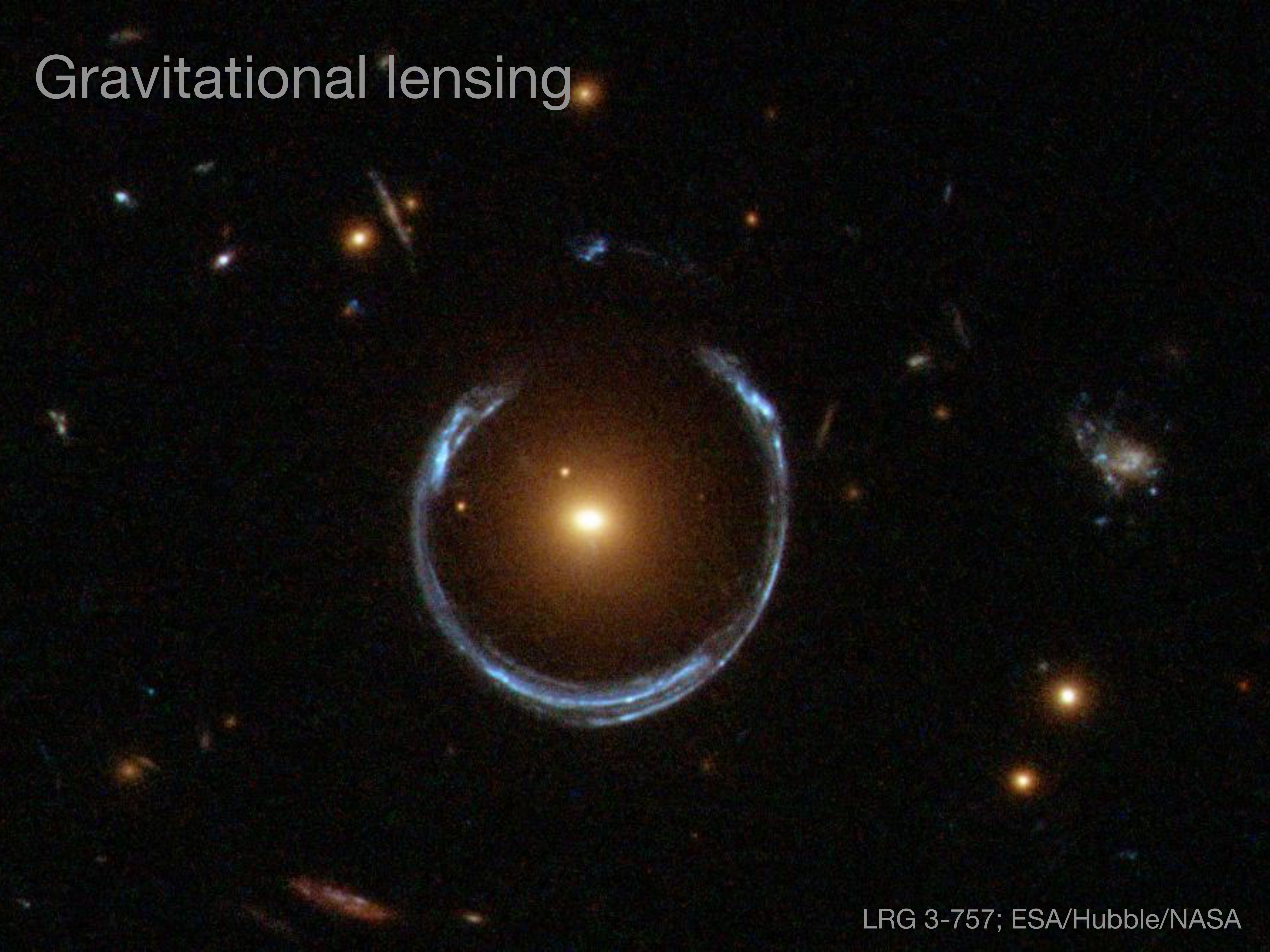




- S5 is likely a very distant red supergiant
- About 1/2 probability to enter the Einstein ring

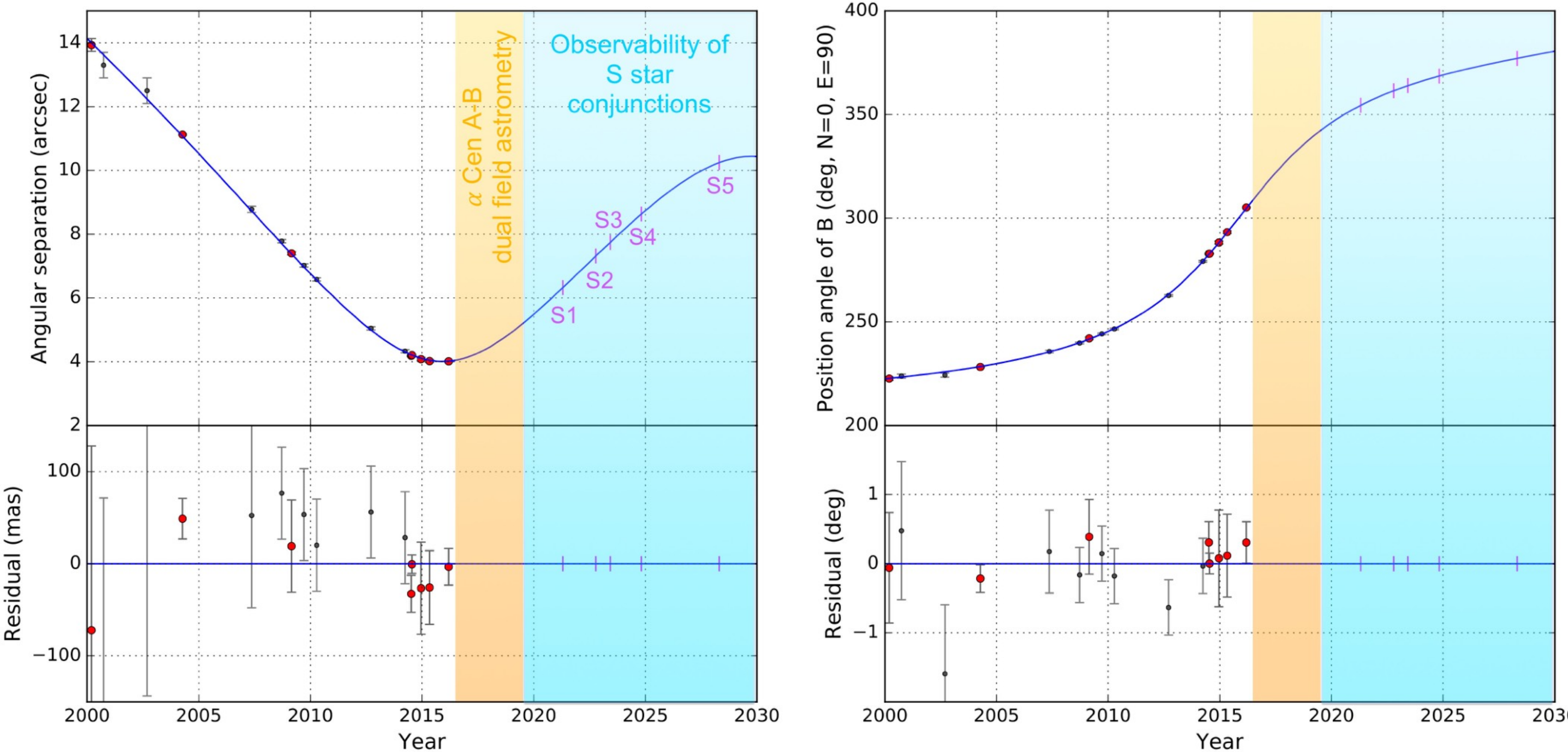
Kervella et al. A&A 594, A107 (2016)

Gravitational lensing



LRG 3-757; ESA/Hubble/NASA

Future α Cen observations with GRAVITY



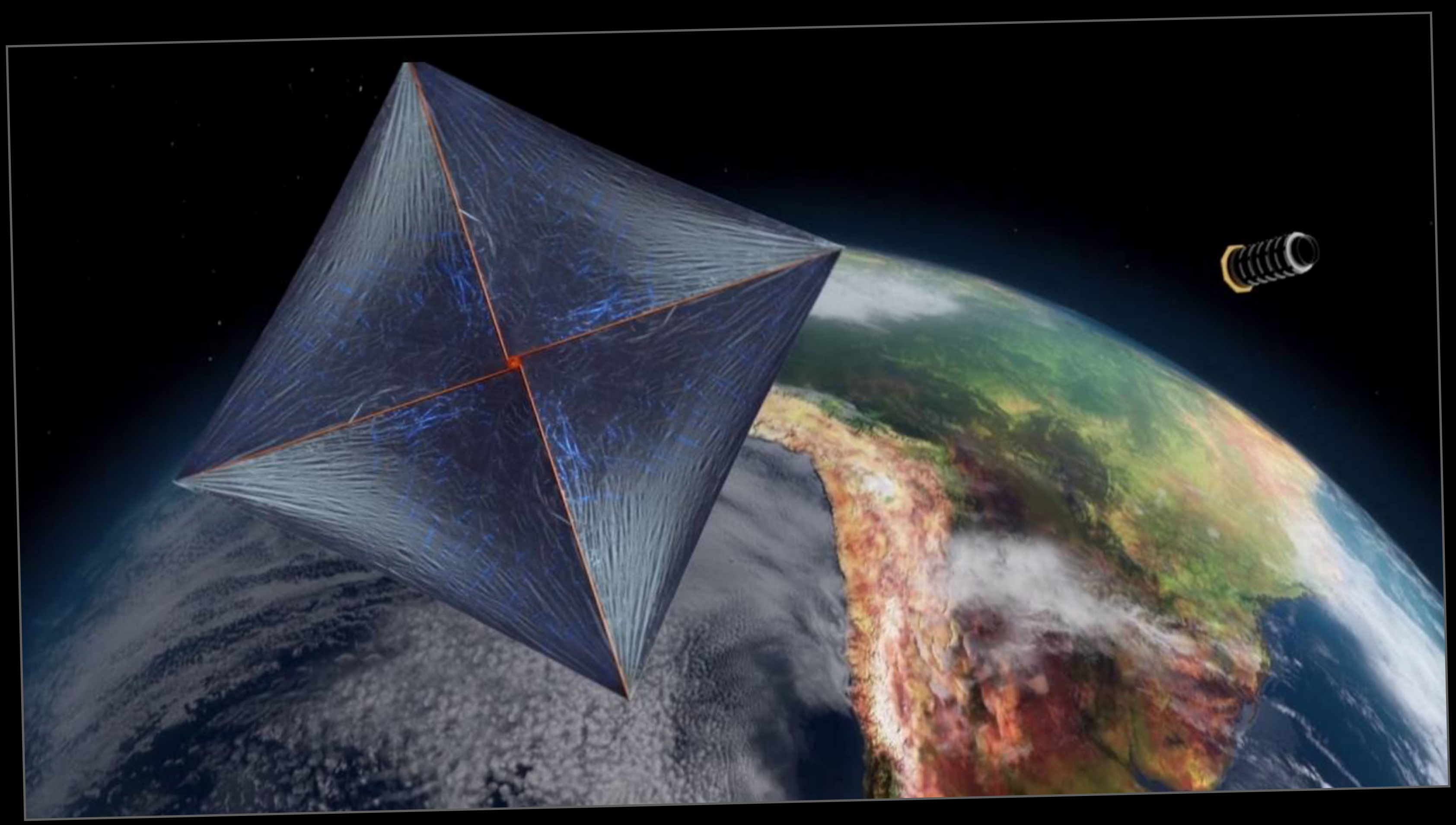
Sensitivity to planets: 2.5 M_{Earth} in the HZ

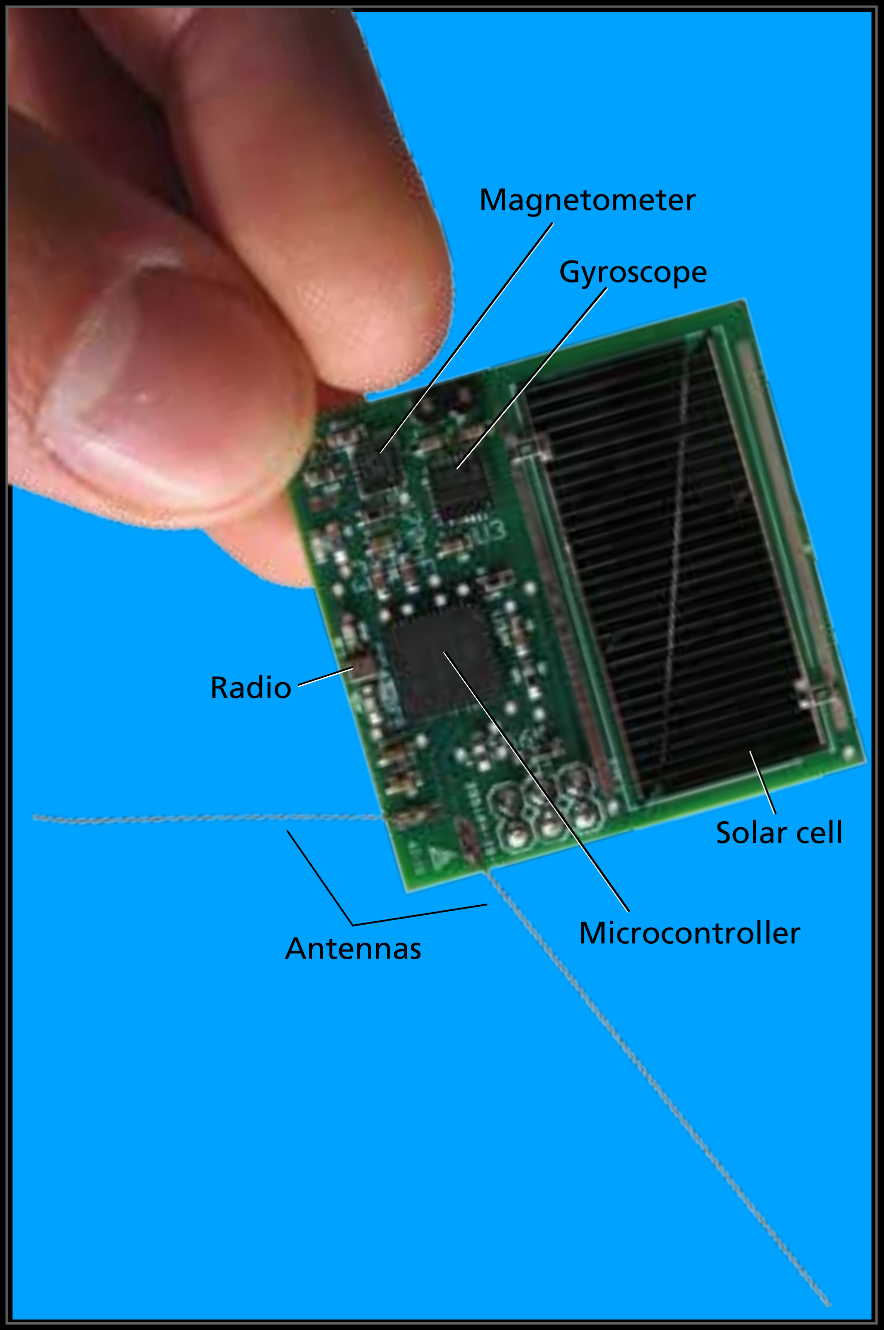
Parallax target accuracy: 10 µas (now 610 µas)

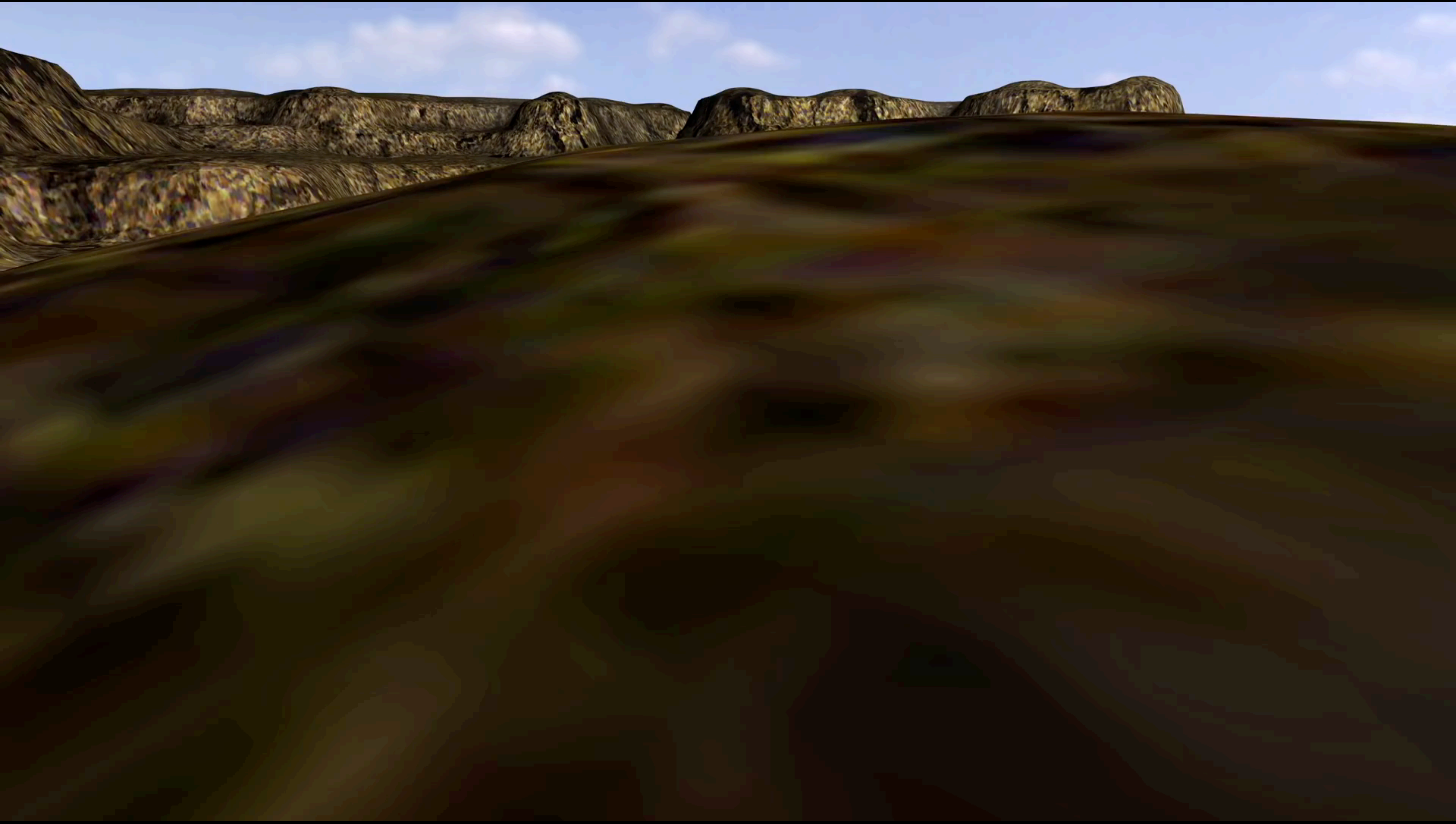
Proper motion accuracy goal: 1 µas / year (now 4 mas/yr)

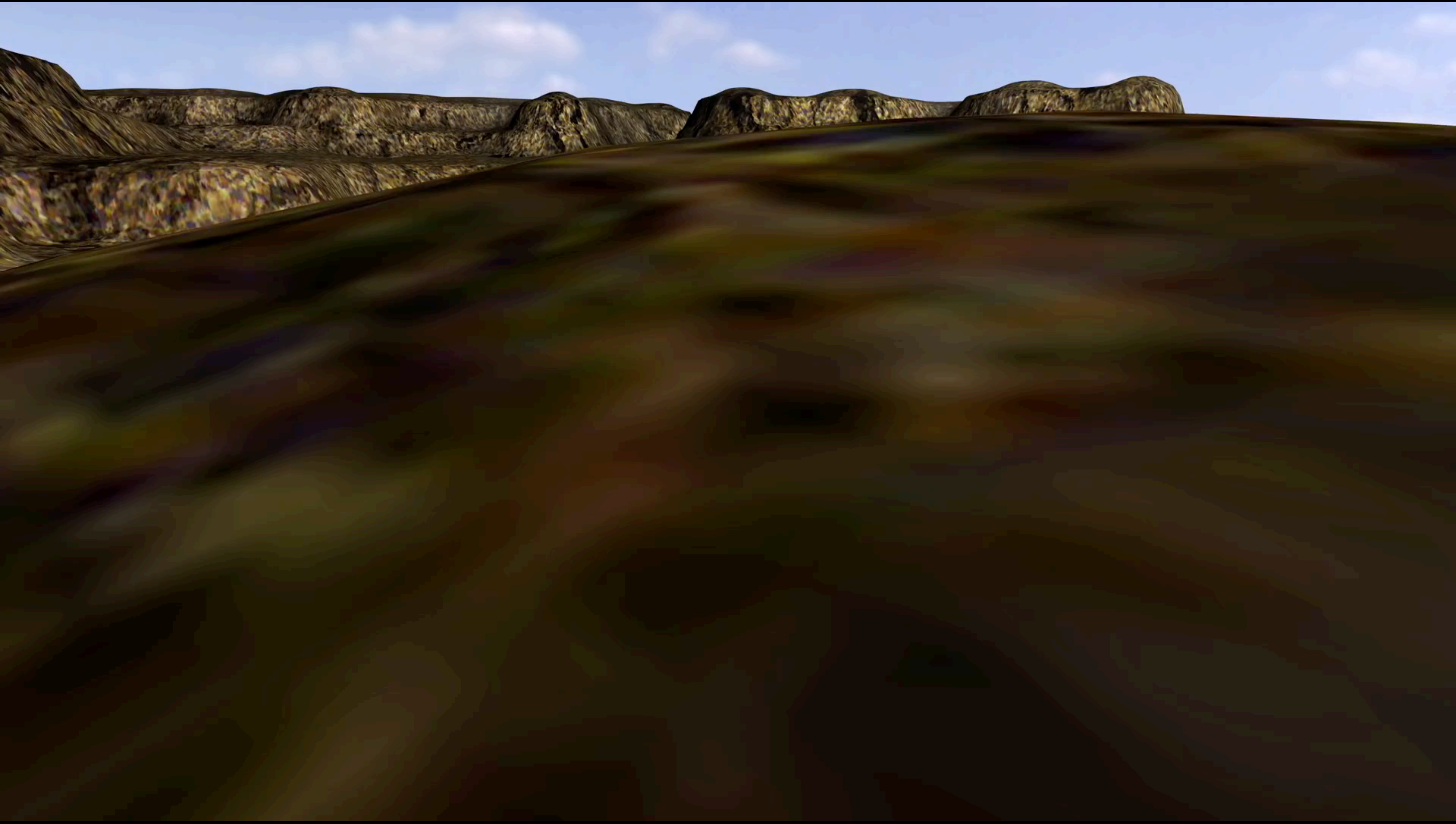
An interstellar probe ?

- Project *Breakthrough Starshot*

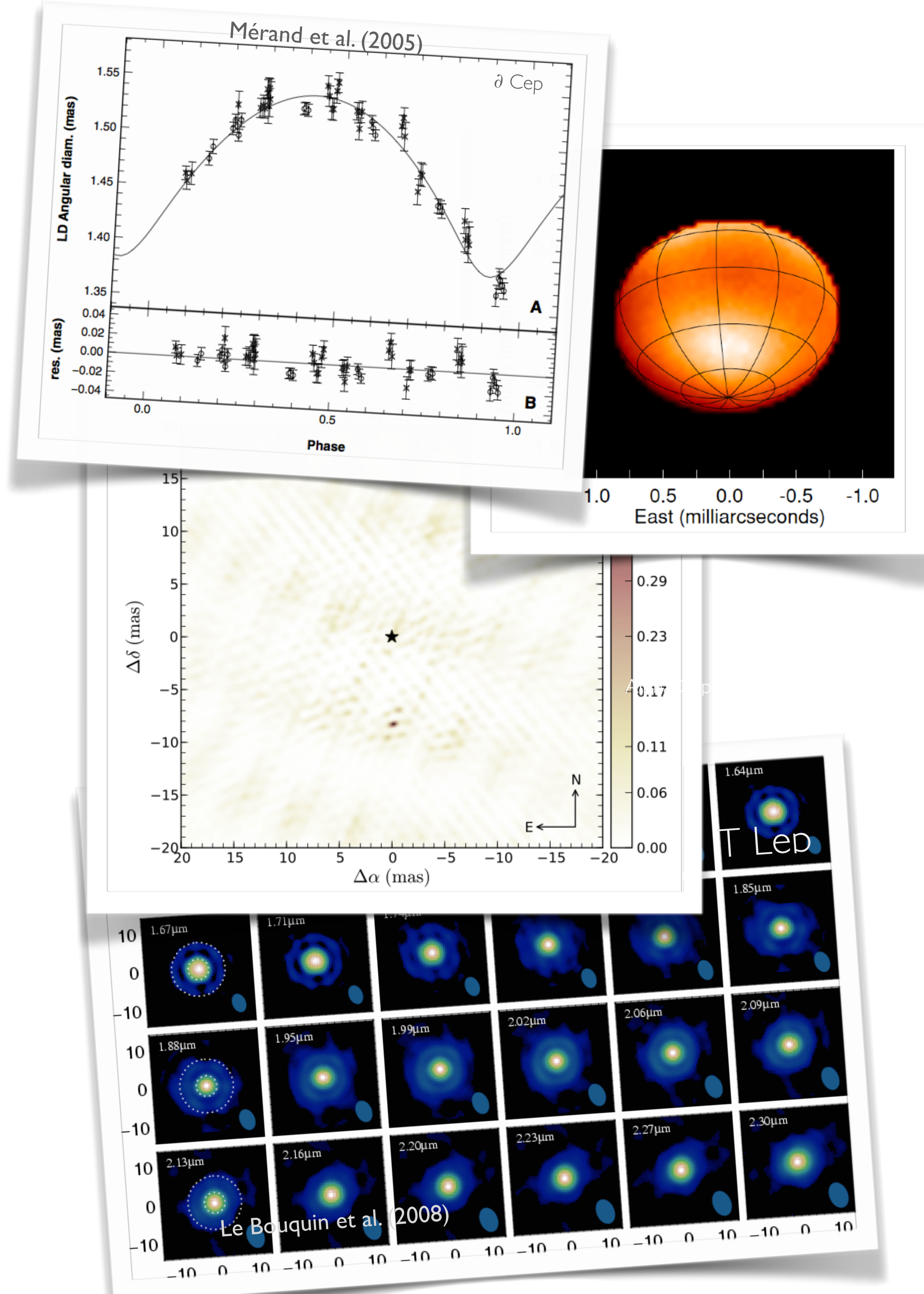








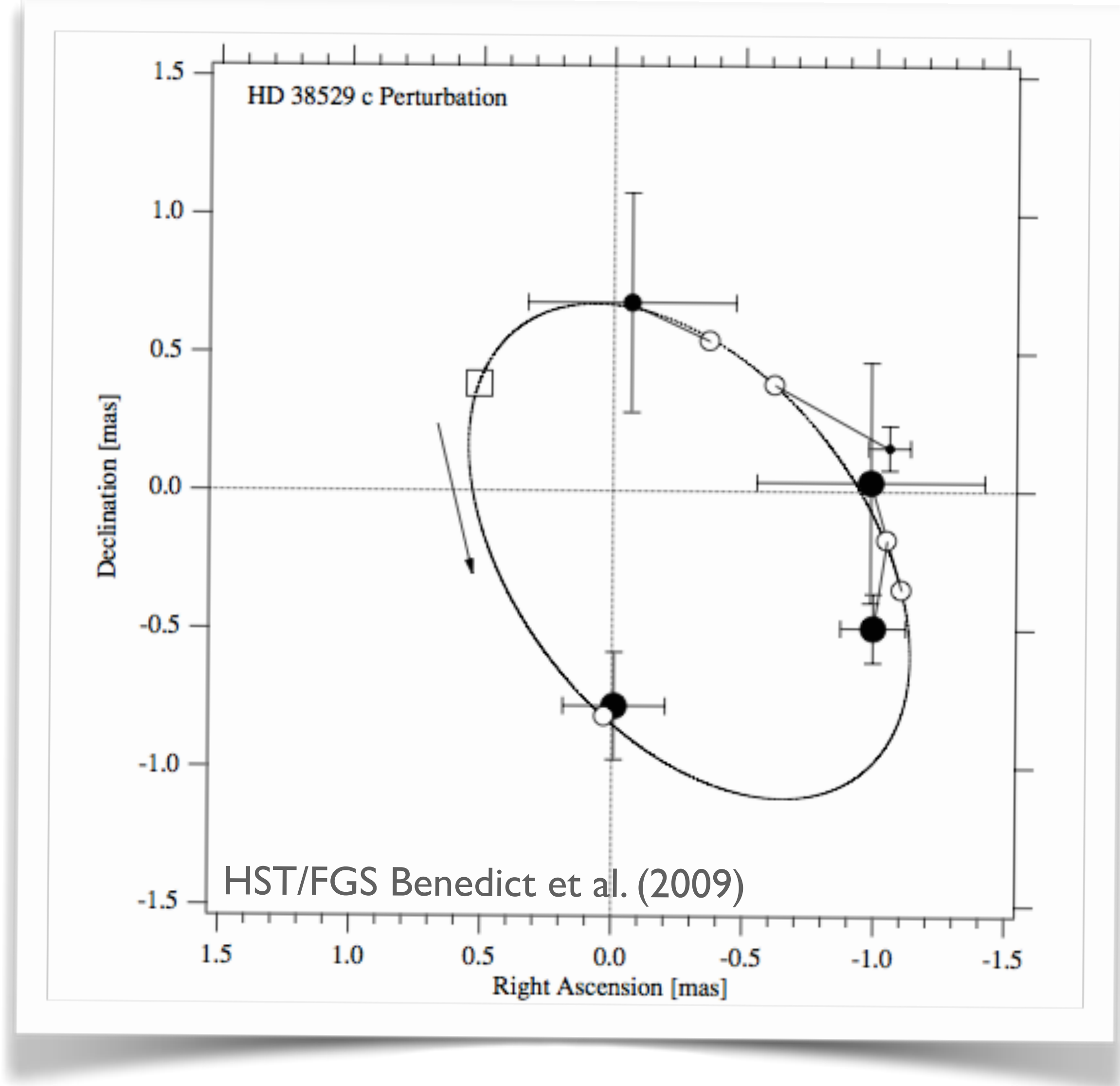
- 4T interferometry (like PIONIER), with spectral resolution (like AMBER)
- Single field sensitivity ~ PIONIER
- Spectro-interferometry of stellar surfaces and environments at spectral resolution 4000
- Within a single field of view (60 / 250 mas)



Exoplanets

Exoplanets

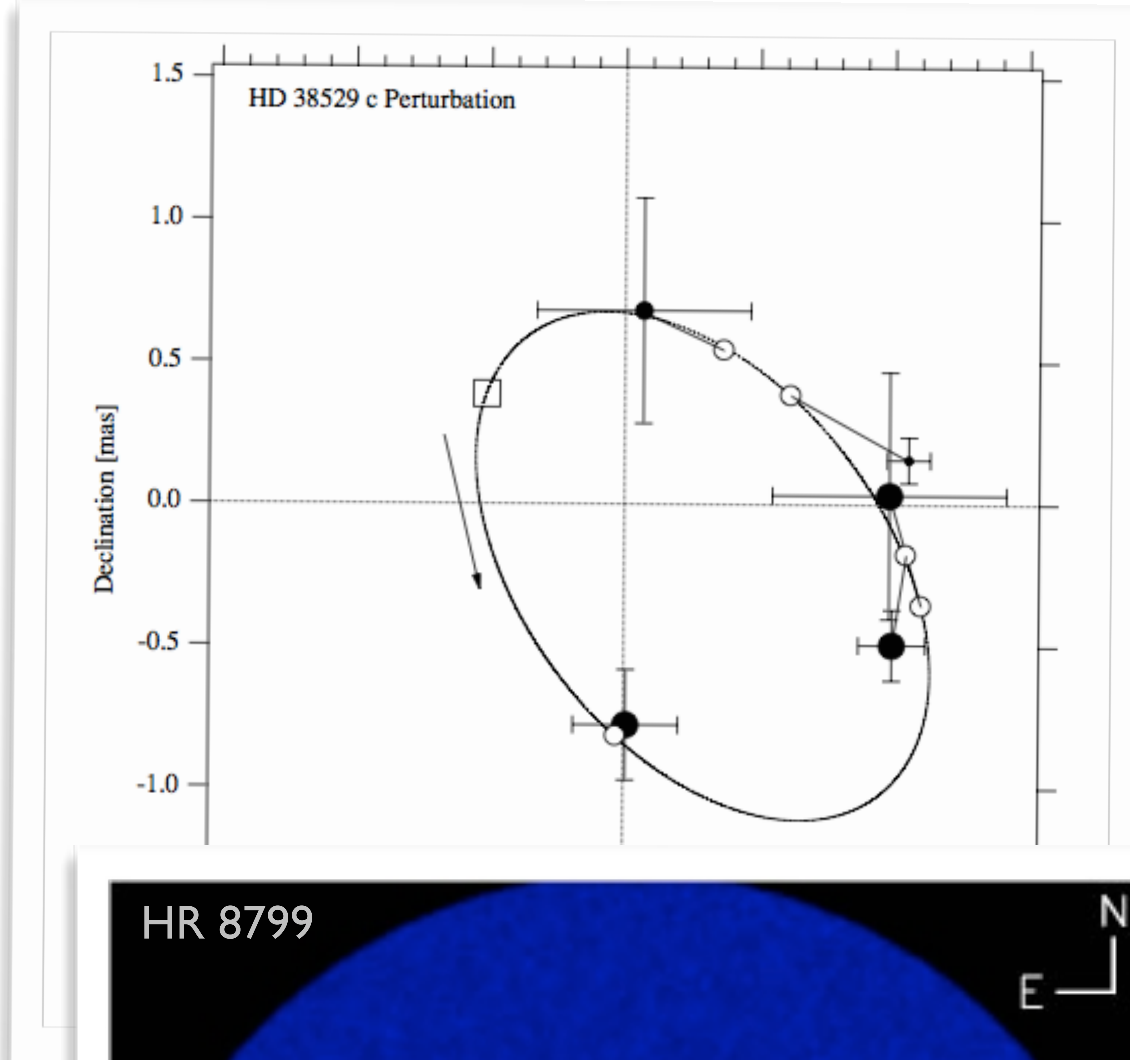
- Astrometric wobble of star ➠ Planet mass

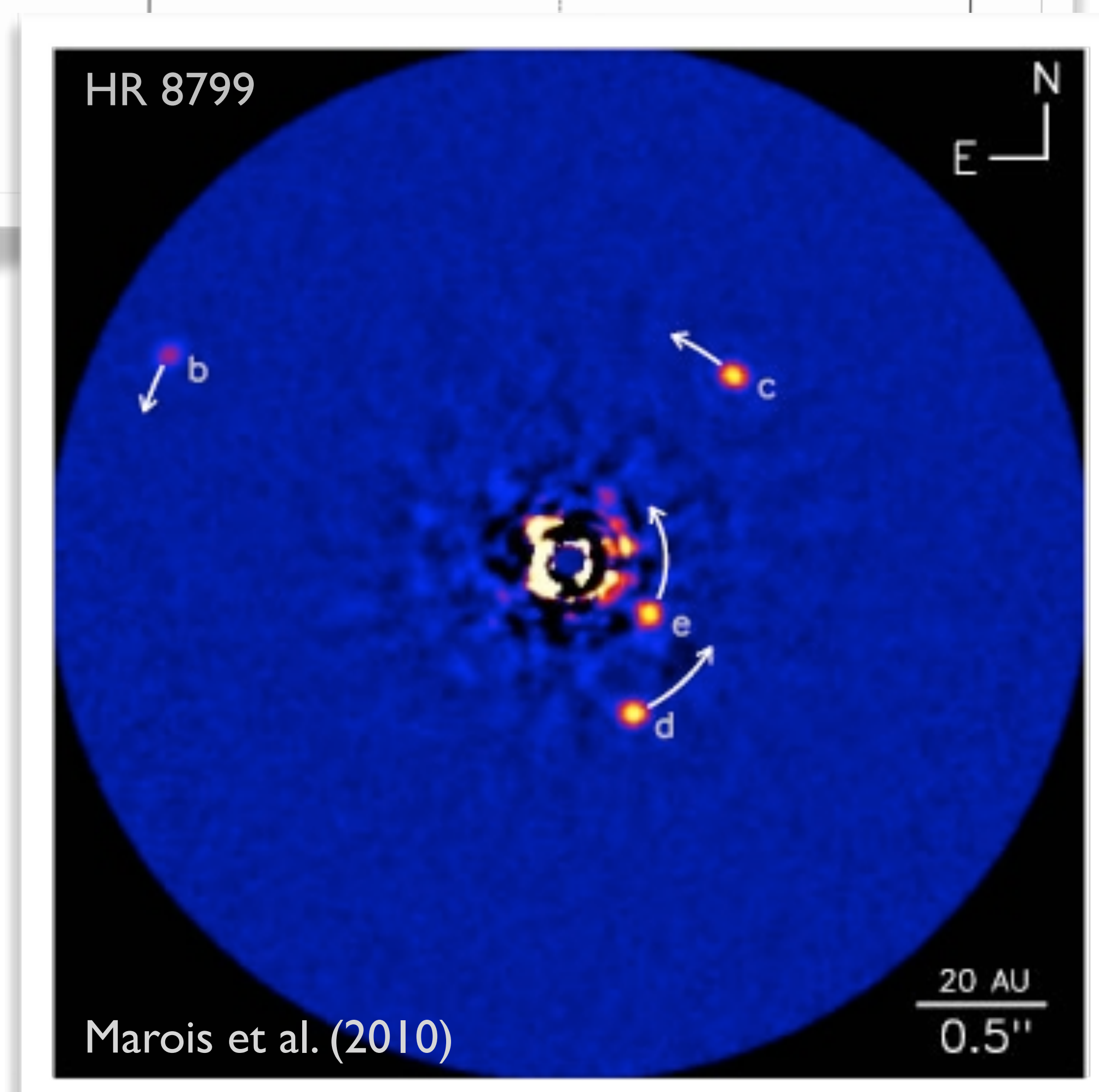


Exoplanets

- Astrometric wobble of star ➠ Planet mass

- Displacement of spatially resolved planets relative to their star ➠ Moons ?





Extragalactic science

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- Astrometry of stars near globular cluster cores

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- Brightest stars in the Magellanic Clouds and their surroundings

Extragalactic science

- Astrometry of stars near globular cluster cores
- Brightest stars in the Magellanic Clouds and their surroundings
- Spectro-imaging of AGN cores (including spectro-astrometry)